

CA1 EP 59077E07

Canada. EPS. WPCD.

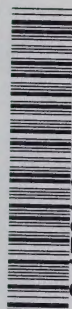
EPS 3-WP-77-7

STATE-OF-THE-ART REVIEW OF PROCESSES FOR TREATMENT AND
REUSE OF POTATO WASTES. 1977.

Pêches et Environnement
Canada

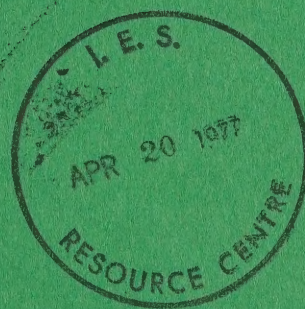
Service de la
protection de
l'environnement

CA 1 EP59077E07



3 1761 05686889 6

State-of-the-Art Review of Processes for Treatment and Reuse of Potato Wastes



Earth Sciences Library

Economic and Technical Review
Report EPS 3-WP-77-7

Water Pollution Control Directorate
March 1977

ENVIRONMENTAL PROTECTION SERVICE REPORT SERIES

Economic and Technical Review Reports relate to state-of-the-art reviews, library surveys, industrial inventories, and their associated recommendations where no experimental work is involved. These reports will either be undertaken by an outside agency or by the staff of the Environmental Protection Service.

Other categories in the EPS series include such groups as: Regulations, Codes and Protocols; Policy and Planning; Technology Development; Surveillance; Briefs and Submissions to Public Inquiries; Training Manuals; and, Environmental Impact and Assessment.

Inquiries pertaining to Environmental Protection Service Reports should be directed to the Environmental Protection Service, Fisheries and Environment Canada, Ottawa K1A 0H3, Ontario, Canada.

SERIE DE RAPPORTS DU SERVICE DE LA PROTECTION DE L'ENVIRONNEMENT

Les rapports sur l'analyse économique et technique concernant des revues de l'état des connaissances, des études documentaires, des inventaires industriels et des recommandations connexes dans des domaines non touchés par le travail expérimental. L'établissement de ces rapports est la responsabilité d'un organisme extérieur ou du personnel du Service de la protection de l'environnement.

La Service compte d'autres séries de rapports: règlements, codes et méthodes d'analyse; politiques et planification; développement technologique; surveillance; exposés et mémoires découlant d'enquêtes publiques; guides de formation; évaluations et effets environnementaux.

Prière d'envoyer toute demande de renseignements ayant trait aux rapports du Service à l'adresse suivante: Service de la protection de l'environnement, Pêches et Environnement Canada, Ottawa K1A 0H3, Ontario.

STATE-OF-THE-ART REVIEW OF PROCESSES FOR
TREATMENT AND REUSE OF POTATO WASTES

by

J.P. Stephenson and P.H.M. Guo
Wastewater Technology Centre
Environmental Protection Service
FISHERIES AND ENVIRONMENT CANADA

Report No. EPS 3-WP-77-7
March 1977

© Minister of Supply and Services Canada 1977

Cat. No.: En43-3/77-7

ISBN 0-662-00559-7

Contract No.: KE204-6-C097

T & H Printers Limited.

ABSTRACT

A review of the literature pertinent to the production and treatment of potato processing wastes is presented. The report outlines the unit operations (fluming, washing, peeling, slicing and blanching) employed in the industry with emphasis being placed on the french fry and potato chip sectors. Data on the quantity and quality of wastes generated from each unit operation were collected and analyzed. Results reported in the literature were compared with those obtained from a questionnaire survey conducted in the Canadian potato processing industry in 1973.

In-plant measures for water conservation, water recycle and by-products recovery have been demonstrated as potential methods for reduction of waste loads. Biological processes such as activated sludge systems, trickling filters, aerated lagoons, waste stabilization ponds and rotating biological contactors were reported to be feasible for the treatment of the potato processing wastes. Land application of sludges produced from biological treatment systems has been most common for sludge disposal.

RÉSUMÉ

L'étude porte sur la documentation se rapportant aux déchets de l'industrie de transformation de la pomme de terre et aux traitements qu'on leur faire subir. Les différents procédés industriels (transport canalisé, lavage, épluchage, tranchage et blanchiment) font l'objet d'un examen, en particulier dans la préparation des pommes de terre frites et des croustilles. Les données quantitatives et qualitatives des déchets résultant de chaque procédé prêtent à une analyse; celles que ont déjà été publiées ailleurs sont comparées aux réponses à un questionnaire envoyé en 1973 à certains établissements canadiens traitant la pomme de terre.

Les mesures prises au sein des établissements pour réduire la consommation d'eau et la recycler ainsi que pour récupérer les sous-produits ont fait leurs preuves, les charges de déchets ayant diminué. Des procédés biologiques comme les boues activées, les lits bactériens, les étangs d'aération, les bassins de stabilisation et les disques d'aération bactérienne se sont révélés applicables au traitement des déchets de pommes de terre transformées. L'épandage des boues résiduelles des systèmes biologiques est la méthode la plus courante de les dissiper.

TABLE OF CONTENTS

	<u>Page</u>
ABSTRACT	i
TABLE OF CONTENTS	iii
List of Figures	v
List of Tables	vii
SUMMARY	viii
 1 INTRODUCTION	 1
 2 COMPOSITION AND STRUCTURE OF THE POTATO TUBER	 3
 3 DESCRIPTION OF THE POTATO PROCESSING INDUSTRY	 7
3.1 Description of the Industry in Canada	7
3.2 Unit Operations in the Potato Processing Industry	7
3.2.1 Fluming and washing	7
3.2.2 Peeling	9
3.2.3 Slicing, separating and washing	11
3.2.4 Blanching	12
3.2.5 Cooking	12
 4 WASTE CHARACTERISTICS	 14
4.1 Fluming and Washing	14
4.2 Peeling	20
4.3 Slicing, Separating and Washing	28
4.4 Blanching	34
4.5 Comparison of Peeler, Slicer and Blancher Wastes	40
4.6 Characterization of the Total Plant Effluent	40
 5 IN-PLANT MEASURES FOR REDUCTION OF WASTES AND RECOVERY OF BY-PRODUCTS	 53
5.1 Fluming and Washing	53

TABLE OF CONTENTS (CONT'D)

	<u>Page</u>
5.2 Peeling	53
5.3 Slicing	54
5.4 Blanching	55
 6 TECHNOLOGY APPLIED TO TREATMENT OF THE TOTAL PLANT EFFLUENT	 58
6.1 Primary Treatment	58
6.2 Biological Treatment	60
6.2.1 Activated sludge	61
6.2.2 Trickling filters	64
6.2.3 Aerated lagoons	66
6.2.4 Waste stabilization ponds	67
6.2.5 Rotating biological contactors	69
6.3 Sand Filtration	71
6.4 Advanced Treatment Methods	71
6.5 Land Disposal	72
6.6 Handling and Disposal of Sludges from Biological Treatment Systems	72
6.7 Summary	74
 REFERENCES	 75
ACKNOWLEDGEMENTS	84

LIST OF FIGURES

<u>Figure</u>		<u>Page</u>
1	Schematic Structures of Amylose and Amylopectin	4
2	Potato Starch Granules	5
3	Typical Unit Operations in Major Potato Processing Sectors	10
4	Distribution of Water Usage in Fluming and Washing Operations	16
5	Distribution of Suspended Solids Concentrations in Fluming and Washing Wastes	17
6	Distribution of BOD ₅ Concentrations in Fluming and Washing Wastes	18
7	Distribution of COD Concentrations in Fluming and Washing Wastes	19
8	Relation of BOD ₅ to COD in Fluming and Washing Wastes	21
9	Distribution of Water Usage from Peeler Operations	23
10	Distribution of Total and Suspended Solids in Peeler Wastes	24
11	Distribution of BOD ₅ and COD Concentrations in Peeler Wastes	25
12	Relation of BOD ₅ to COD in Peeler Wastes	26
13	Relation of BOD ₅ to Suspended Solids in Peeler Wastes	27
14	Distribution of Suspended Solids and BOD ₅ Loads in Peeler Wastes	29
15	Distribution of Water Usage from Slicer Operations	31
16	Distribution of Total and Suspended Solids in Slicer Wastes	32
17	Distribution of BOD ₅ and COD Concentrations in Slicer Wastes	33

LIST OF FIGURES (CONT'D)

<u>Figure</u>		<u>Page</u>
18	Relation of BOD ₅ to Suspended Solids in Slicer Wastes	35
19	Distribution of Water Usage from Blancher Operations	37
20	Distribution of COD and Total Solids Concentrations in Blancher Wastes	38
21	Relation of COD to Total Solids in Blancher Wastes	39
22	Comparison of Water Usages in Various Unit Operations	41
23	Comparison of BOD ₅ Concentrations in Various Unit Operations	42
24	Comparison of Suspended Solids Concentrations in Various Unit Operations	43
25	Distribution of the Total Water Usage in Potato Processing Plants	47
26	Distribution of BOD ₅ and COD Concentrations in Total Plant Effluents	48
27	Distribution of Total and Suspended Solids in Total Plant Effluents	49
28	Relation of BOD ₅ to Suspended Solids in Total Plant Effluents	50
29	Relation of BOD ₅ to COD in Total Plant Effluents	51
30	Relation of COD, Starch and Sugar Concentrations to Multiple Reuse of the Blancher Waste	56

LIST OF TABLES

<u>Table</u>		<u>Page</u>
1	Composition of White Potatoes	3
2	Number of Canadian Potato Processing Plants by Region and Product	8
3	Potato Products Sold in 1970	9
4	Potato Losses in Various Peeling Operations	12
5	Characteristics of Fluming and Washing Wastes	15
6	Characteristics of Peeler Wastes	22
7	Characteristics of Slicer Wastes	30
8	Characteristics of Blancher Wastes	36
9	Comparison of Peeler, Slicer and Blancher Wastes	40
10	Characteristics of Total Plant Effluents	45
11	Comparison of Data from Questionnaire and Literature	52
12	Primary Clarification of the Total Plant Effluent	59
13	Activated Sludge Treatment of Potato Processing Wastes	62
14	Trickling Filter Treatment of Potato Processing Wastes	65
15	Aerated Lagoon Treatment of Potato Processing Wastes	68
16	Waste Stabilization Pond Treatment of Potato Processing Wastes	70

SUMMARY

An extensive literature review indicates that numerous alternatives exist for reduction and treatment of wastewaters from the potato processing industry. The following summary identifies typical wastewater characteristics, water consumption, in-plant methods for reduction of waste load and existing technology for the treatment of the potato processing waste:

1. Frozen french fry and potato chip manufacturers accounted for the majority of the total quantity of potatoes processed in Canada. Based on the literature review, 27 kg (54 lb) BOD₅ and 30 kg (60 lb) suspended solids were produced per tonne* of potatoes processed. Results of a questionnaire distributed to the Canadian potato processing industry indicated that, for each tonne of potatoes processed, only 13 to 16 kg (26 to 32 lb) BOD₅ and 15 to 16 kg (30 to 32 lb) suspended solids were generated.
2. A median water usage of 15×10^3 l/t (3000 gal**/ton) was reported in the literature. Results of the questionnaire indicated that only 6.4 to 7.3×10^3 litres of water was used per tonne (1280 to 1460 gal/ton) of potatoes processed in the Canadian potato processing industry.
3. For each tonne of potatoes processed, 8.4, 5.6 and 3.5 kg (16.8, 11.2 and 7.0 lb) of median BOD₅ and 10.8, 3.7 and 0.4 kg (21.6, 7.4 and 0.8 lb) of median suspended solids were generated from the peeling, slicing and blanching operations, respectively.
4. Process modifications to reduce the water usage and in-plant treatment of wastewaters from the peeling and slicing operations resulted in a significant reduction of BOD₅ and suspended solids. Solids recovered from the in-plant treatment have been used successfully as cattle feed.

* 1 tonne = 1000 kg.

** Imperial gallons used throughout the text.

5. The median BOD₅ and suspended solids concentrations of the total plant effluent were approximately 1800 and 2000 mg/l, respectively. Fine screens ranging from 10 to 325 mesh removed 10 to 85% suspended solids. Substantial reduction in the BOD₅ concentration, up to 70%, was achieved by screening.
6. Primary clarification of the total plant effluent reduced 29 to 52% of BOD₅ and 50 to 94% of suspended solids. The settled sludge could be dewatered and recovered as cattle feed.
7. The activated sludge process has been most commonly used for treatment of the potato processing waste. Satisfactory performance could generally be achieved at organic loadings less than 0.5 kg BOD₅/kg MLSS•day. For treatment systems operated at higher organic loadings, bulking sludge problems were encountered.
8. Conventional and synthetic media trickling filters had varying degrees of success in the treatment of potato processing wastes. Effluent BOD₅ ranging from 61 to 350 mg/l and suspended solids from 39 to 140 mg/l were attained in the trickling filters operated at 0.06 to 4.6 kg BOD₅/m³•day. The rotating biological contactor has been shown to be feasible for the treatment of potato wastes; however, available data are limited and future research in this area is required.
9. Aerated lagoons operated at loadings ranging from 189 to 440 kg BOD₅/ha•day removed 55 to 82% BOD₅ with effluent concentrations being from 70 to 710 mg/l. The use of single-stage anaerobic waste stabilization ponds was usually not satisfactory. Significant improvement in the treatment efficiency could be achieved in a combined system using a waste stabilization pond and an aerated lagoon.
10. In areas where sufficient land and proper soil type are available, application of potato processing wastes to the soil provides an alternative for waste disposal. To avoid

clogging soil pores, measures should be taken to control the discharge of the caustic peeler waste containing a high concentration of sodium ions.

11. For conditioning of sludges produced from biological systems treating potato wastes, chemical addition, centrifugation and vacuum filtration are practised. Aerobic digestion reduces organic solids and improves sludge dewaterability. Land application is the most common method of sludge disposal.
12. Although reverse osmosis, evaporation and ion exchange are commonly used in the potato starch industry for by-products recovery, the application of these advanced methods for the treatment of potato processing wastes has as yet not been shown to be cost effective.

INTRODUCTION

In 1970, Canadian farmers produced 2,510,000 tonnes (2,760,000 tons) of field potatoes grown on 130,000 hectares (320,000 acres) of agricultural land (1, 2). The provinces of New Brunswick, Ontario, Prince Edward Island, and Quebec accounted for about 76% of this country's gross yield. It is significant that the potato crop accounts for a larger farm cash value than the total of all other fruit and vegetable crops grown in Canada (3). In addition, a large part of the production is sold for processing into a variety of foodstuffs including frozen french fries, potato chips, and dehydrated potatoes. Smaller amounts are used for the production of other products including whole canned potatoes, potato starch and potato snack items.

Like many food processing industries, the potato processing industry produces solid and liquid wastes. Large volumes of water are used to transport and process potatoes; a consequence of the processing stage is the generation of a high biochemical oxygen demand (BOD_5) and suspended solids (SS) load in the process effluent. Of particular concern is the solid waste generated in the potato peeling operation. If caustic peeling is employed, the peel waste and total plant effluent frequently have a pH exceeding 11. The principal pollutant from a potato processing operation is starch. One kg (2.2 lb) of potato solids, largely composed of starch, can exert 4.5 kg (9.9 lb) BOD_5 . It has been shown that one tonne of processed potatoes produces waste equivalent to a population of approximately 300 people (4, 5).

Process modifications for recovery of starch and reuse of process water can reduce effluent volume and organic load. Significant reductions can also be obtained by a variety of waste treatment processes. Without treatment these wastes can cause serious environmental problems in waterways, or may overload existing municipal sewage treatment systems.

To assist in developing Canadian effluent guidelines and regulations for the potato processing industry, an extensive literature review was undertaken to collect information on the production and

treatment of wastes generated in the industry. The objectives of this literature review were:

1. to provide a brief description of the important sectors of this industry in Canada;
2. to determine quantities and characteristics of wastes from different unit operations in these sectors;
3. to estimate the quantities and characteristics of the total plant effluent;
4. to identify demonstrated in-plant measures for reduction of waste loads and recovery of by-products; and
5. to identify existing treatment technology for the reduction of waste constituents from the potato processing industry.

COMPOSITION AND STRUCTURE OF THE POTATO TUBER

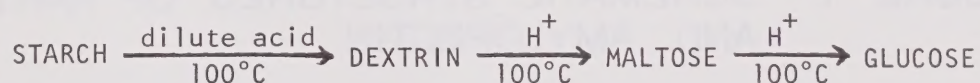
To assist in the understanding of the type of waste involved, a synopsis of the chemical and physical properties of the potato is presented.

The bulk of potato is water (77.5%) with the major portion of the solid fraction existing as starch. Table 1 indicates the composition of white potatoes (6). The starch content comprises 65 to 80% of the total dry solids, and exists as 20% soluble amylose and 80% insoluble amylopectin (7). The amylose is a colloidal dispersion resulting from the disruption of starch granules by heating or physical action (8). Figure 1 depicts the molecular structures of the amylose and amylopectin fractions in the starch granule. Typical starch granules are shown in Figure 2.

TABLE 1. COMPOSITION OF WHITE POTATOES (6)

Constituent	Composition (%)	
	Average	Range
Water	77.5	63 - 87
Carbohydrate	19.4	13 - 31
Protein	2.0	0.7 - 5.6
Fat	0.1	0.02 - 1.0
Ash	1.0	0.44 - 1.9

Starches are high molecular weight carbohydrates. They can be broken down chemically from the relatively insoluble complex polysaccharide to more soluble monosaccharides by hydrolysis in dilute acid at 100°C. This hydrolysis is illustrated as follows:



Alternatively, the enzyme diastase may directly break down this polysaccharide to the disaccharide maltose and then to the monosaccharide glucose by further hydrolysis with the enzyme maltase.

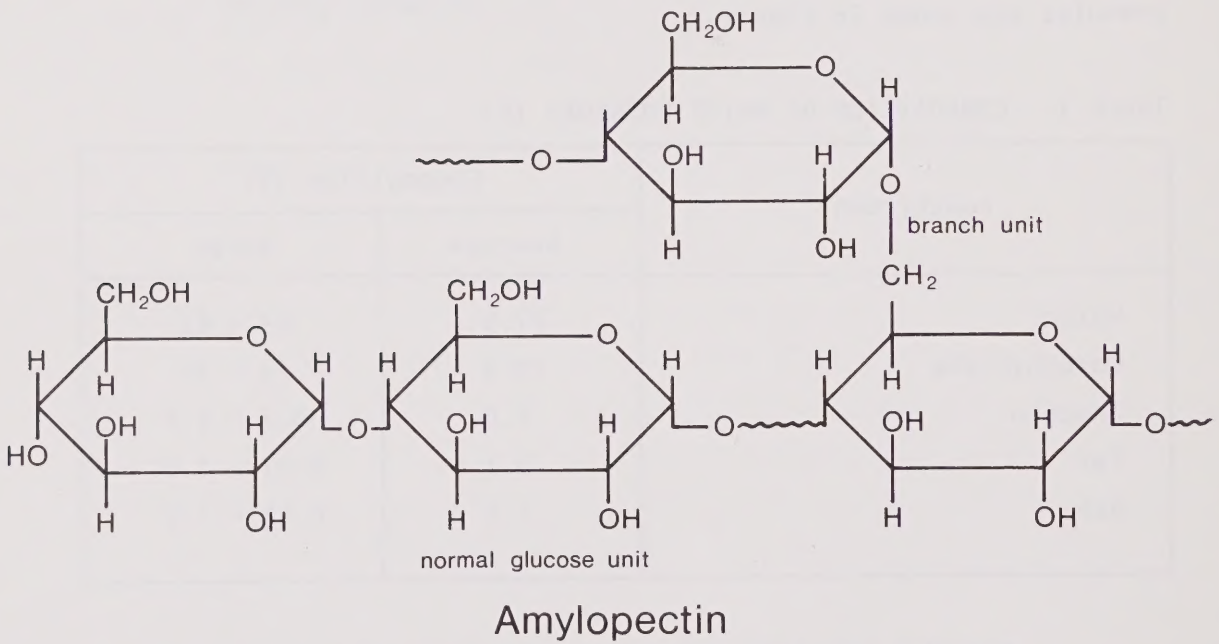
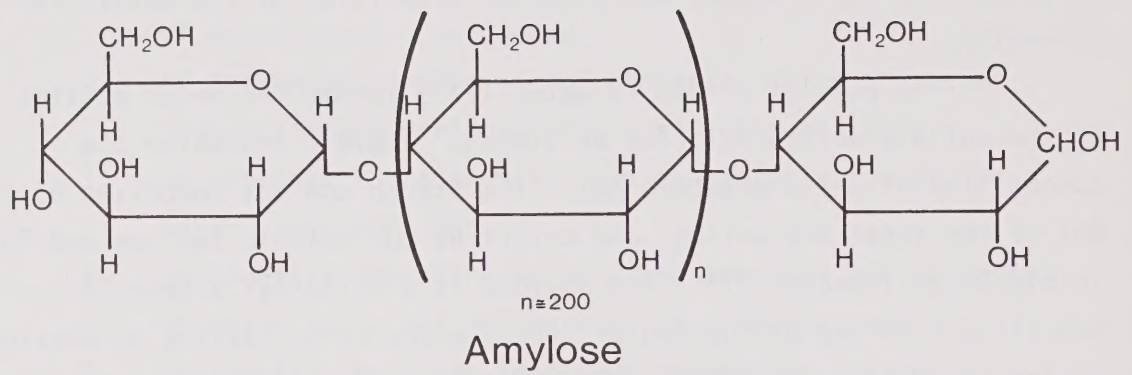


FIGURE 1. SCHEMATIC STRUCTURES OF AMYLOSE AND AMYLOPECTIN



FIGURE 2. POTATO STARCH GRANULES (6)



In each case, the end product is glucose. In a biological system, two enzymes α -amylase and phosphorylase, act upon starch components to produce degradation products more easily assimilated by microorganisms (9).

Other compounds are also present. The reducing sugar content of white potatoes reaches a maximum of 10% of the potato's dry weight with sucrose, glucose, and fructose being predominant. To prevent enzymatic action which results in discolouration, these substances are blanched or leached from raw, sliced potatoes during the production of french fried and dehydrated products. It is these leached, soluble sugars which exhibit a high BOD_5 in the waste stream. With respect to nitrogen, it is known that 2% of the potato's weight is protein, and accounts for one-third to one-half of the total nitrogen present. The remaining nitrogen is largely in the form of free amino acids. Phosphorus, potassium and other elements are present in smaller quantities.

In potato wastes, the nutrients (C, N, P) necessary for biological waste treatment are present in approximately balanced proportions. Based on the composition of potatoes and assuming that each gram of dry solids in potatoes contributes 0.45 g of BOD_5 (4), the nutrient ratio was calculated to be:

$$\text{BOD}_5:\text{N}:\text{P} = 100:6.2:0.64$$

This ratio compares favourably with the generally accepted ratio of 100:5:1 used in a biological treatment system. Although the phosphorus content is slightly lower than the desired amount, there is no documented evidence of a nutrient limiting situation for successful biological treatment of this type of waste.

3 DESCRIPTION OF THE POTATO PROCESSING INDUSTRY

3.1 Description of the Industry in Canada

The Canadian potato processing industry is basically divided into two main sectors: frozen french fry and potato chip. These account for the greatest portion of potatoes processed, and the greatest number of individual process plants. Dehydrated potato products such as instant potato flakes, slices and dices belong to a third sector. While the potato starch industry was once present in Canada, it has now virtually disappeared. A minor portion of the gross quantity of potatoes processed is directed into other products such as whole canned potatoes and potato snack items. Table 2 shows an inventory of the number of potato processing plants in Canada (10). Table 3 lists the three most important potato products processed and sold in Canada with respect to quantities and cash values.

While in terms of potato products sold by various food processors, frozen french fries comprised the largest bulk, potato chips represented the highest cash value during 1970 (11).

3.2 Unit Operations in the Potato Processing Industry

In the potato processing industry, some variation in the unit operations employed by different companies exist. However, most of the unit operations used are common to each sector of the industry.

The production of potato products consists of three distinct stages: storage, processing and packaging. The processing stage is most important from a waste generation point of view, and can be subdivided into a number of unit operations. A typical arrangement of the stages and unit operations in the major potato processing sectors is shown in Figure 3. A more complete description can be found elsewhere (6).

3.2.1 Fluming and washing

Field potatoes are harvested in the fall and shipped to environmentally controlled warehouses for storage. Temperature and humidity control in storage have been shown to play an important part

TABLE 2. NUMBER OF CANADIAN POTATO PROCESSING PLANTS BY REGION AND PRODUCTS (10)

REGION PRODUCT	PACIFIC	NORTHWEST	ONTARIO	QUEBEC	ATLANTIC	NATIONAL
FRENCH FRIES	3	3	2	2	4	15
CHIPS	2	3	4	8	2	19
DEHYDRATED PRODUCTS	-	1	1	-	-	2
STARCH	-	1	-	-	-	1
OTHER *	2	4	-	3	2	11
TOTAL	7	12	7	13	8	48

* Usually fresh bagged, canned or whole potatoes.

in the quality control of the potato reaching the processing line. The storage condition also significantly affects the quantity and quality of wastewaters generated (6).

TABLE 3. POTATO PRODUCTS SOLD IN 1970 (11)

Product	Quantity Sold		Cash Value	
	Tonnes	%	\$ x 10 ⁶	%
Frozen French Fries	95,690	62	31.1	27
Potato Chips	45,350	29	74.3	66
Dehydrated Products	13,380	9	8.0	7
Total	154,420	100	113.4	100

Transport of potatoes to the process line may be accomplished in two ways: water flumes or tote boxes. During this unit operation, washing is performed by turbulence and abrasion in the transporting medium. In all sectors of the industry, potato washing is always carried out prior to processing. Mechanical size classification may also accompany this unit operation. High water usage is common, and a high inorganic solids load results. Details of the process may be found elsewhere (6, 12).

3.2.2 Peeling

Depending on the final product desired, the peeling operation may be performed in one of three ways:

1. caustic peeling; conventional or dry;
2. steam peeling; or
3. abrasive peeling.

Conventional caustic peeling consists of using a 10 to 20% lye solution, at 60 to 90°C with a 1 to 6 minutes immersion time. This process is usually applied when the outer surface area of the potato is an important factor in the appearance of the final product (13).

This is apparent in french fry production where the ends of the slices are readily visible, and in flake production where a product without skin and fibre is desirable.

The process of "dry" caustic peeling is a recent development in the potato industry, and was designed to eliminate the water usage in the peeling operation after caustic treatment (13, 14, 15, 16, 17). This is accomplished by infrared radiation and mechanical brushes. Not only are small volumes of water required, but significant reductions, ranging from 65 to 80%, in the total amount of caustic are realized with the dry caustic system (15).

Because of the efficient removal of the potato peel, both conventional and dry caustic peeling are popular. However, a waste with a pH in excess of 11 is produced.

Steam peeling is not extensively used in the Canadian industry. It consists of softening the outer potato surface with steam and subsequent removal of the loosened peel by high pressure water jets.

Abrasive peeling is commonly employed in potato chip production. Here, complete skin removal is less important for visual appearance due to the thin nature of the slices. Rotating brushes with the assistance of high pressure water jets aid in the peel removal.

For all types of peeling operations, up to 25% of the raw potato may be lost, but a range of 10 to 18% is considered the median (5, 6). A summary of peel losses from various operations is presented in Table 4. As indicated, the potato loss from the dry caustic peeling is less than that from the wet caustic operation. The wide range of the potato loss from abrasive peeling could be attributable to different degrees of abrasion employed in the peeling operation.

3.2.3 Slicing, separating and washing

Following the initial washing and peeling, the potato size is reduced. The size reduction is a function of the type of final product desired. To ensure uniformity in product size in the french fry and potato chip industry, size classifiers are used. As the

potato size is reduced, the adhering surface starch becomes increasingly more evident and causes slices to cling together if insufficiently washed. This starch represents a substantial organic load in the waste stream from the slice washing operation, and is dependent on the degree of size reduction, duration, and vigour of washing. After sizing, the potato pieces are subjected to either a blanching or a cooking/frying operation.

TABLE 4. POTATO LOSSES IN VARIOUS PEELING OPERATIONS (5)

Peeling Method	Percent of Potato Loss by Weight
Conventional Caustic	17 - 22
Dry Caustic	10 - 13
Steam	10 - 18
Abrasive	7 - 25

3.2.4 Blanching

The objective of the blanching operation is to produce a light, uniformly coloured product. Water at 70 to 77°C is used to leach reducing sugars, inorganic salts, gelatinized starch, and smaller amounts of proteins and amino acids. The mealiness and texture of the potato is partly controlled with an immersion time of 15 to 25 minutes (13). Waste flows are lower in volume than those from the peeling and slicing operations, but are higher in soluble BOD₅, chemical oxygen demand (COD), and dissolved solids. The soluble nature of the waste makes it more difficult to reduce by in-plant management methods. The blanching operation is not used by the potato chip industry.

3.2.5 Cooking

French fries and potato chips are deep fried in fat at temperatures of approximately 177 to 190°C, reducing moisture contents to about 65 and 2%, respectively (6, 14). Steam is used for cooking of dehydrated products, and thus generates a negligible waste volume.

The frying operation; however, generally leads to air pollution problems. Vent gas scrubbing introduces a waste stream of low volume which can be segregated from the remainder of the plant effluent.

Final drying and packaging of all varieties of potato products discussed herein result in negligible liquid waste production.

4 WASTE CHARACTERISTICS

Having identified and described the fundamental unit operations for the three sectors of the potato processing industry, it is relevant to characterize the wastes generated from the industry. Only those unit operations which generate a substantial portion of the total plant waste load will be considered. Most of the data has been extracted from the Canadian, United States, and United Kingdom literature.

As insufficient data are available in the literature to quantify the wastewater generated in each unit operation, process water usages which were well documented are used in the report to provide this information. Generally, this gives a close estimation of the waste volume produced.

4.1 Fluming and Washing

Large quantities of water are used in fluming and washing raw, unpeeled potatoes. Inorganic soil and some organic debris are removed in the operation. The organic load is considered to be of minor importance in this waste stream, thus making it amenable to separate treatment and reuse (18). Characteristics of wastes from the fluming and washing operation are summarized in Table 5. Figure 4 is a log-probability plot relating washwater usage to the expected frequency of occurrence. Figures 5, 6 and 7 represent similar relations for suspended solids, BOD_5 , and COD. Data from potato washing in the starch industry has also been included, since it is the same operation as that for the other sectors. In each case, the data exhibit relatively large ranges. Lower values for water usage generally indicate that a system for recycle has been established (18, 19). From Figure 4, the median value for water usage is estimated to be 1300 l/t. Similarly, the suspended solids, BOD_5 , and COD concentrations have median values of about 2300, 400, and 780 mg/l, respectively. BOD_5 and COD median values are dominated by a wide range as shown in Figures 6 and 7. The high values cannot be attributed to any specific product as shown in the figures. It is significant to note that in the case of BOD_5 , over 50% of the individual data points fall below 220 mg/l. This clearly

TABLE 5. CHARACTERISTICS OF FLUMING AND WASHING WASTES

Reference	Product	Water Usage (l/t)	pH	COD (mg/l)	BOD ₅ (mg/l)	Total Solids (mg/l)	Suspended Solids (mg/l)
19	dehydrated flakes	1630	7.2	990	185	7750	1320
19	chips	3120	7.3	3470	1080	9010	2760
19	starch	2350	6.8	9880	3740	12870	8150
20	french fries	790*	-	-	-	-	-
21	-	5250-6300	7.0	100-250	-	700	-
18	-	5040	6.8	400	220	-	2000
5	-	294	-	-	850	-	3420
22	-	168	-	-	-	-	-
23	-	630*	-	260	100	-	-
24	-	-	-	-	130	-	310

* Recycle system.

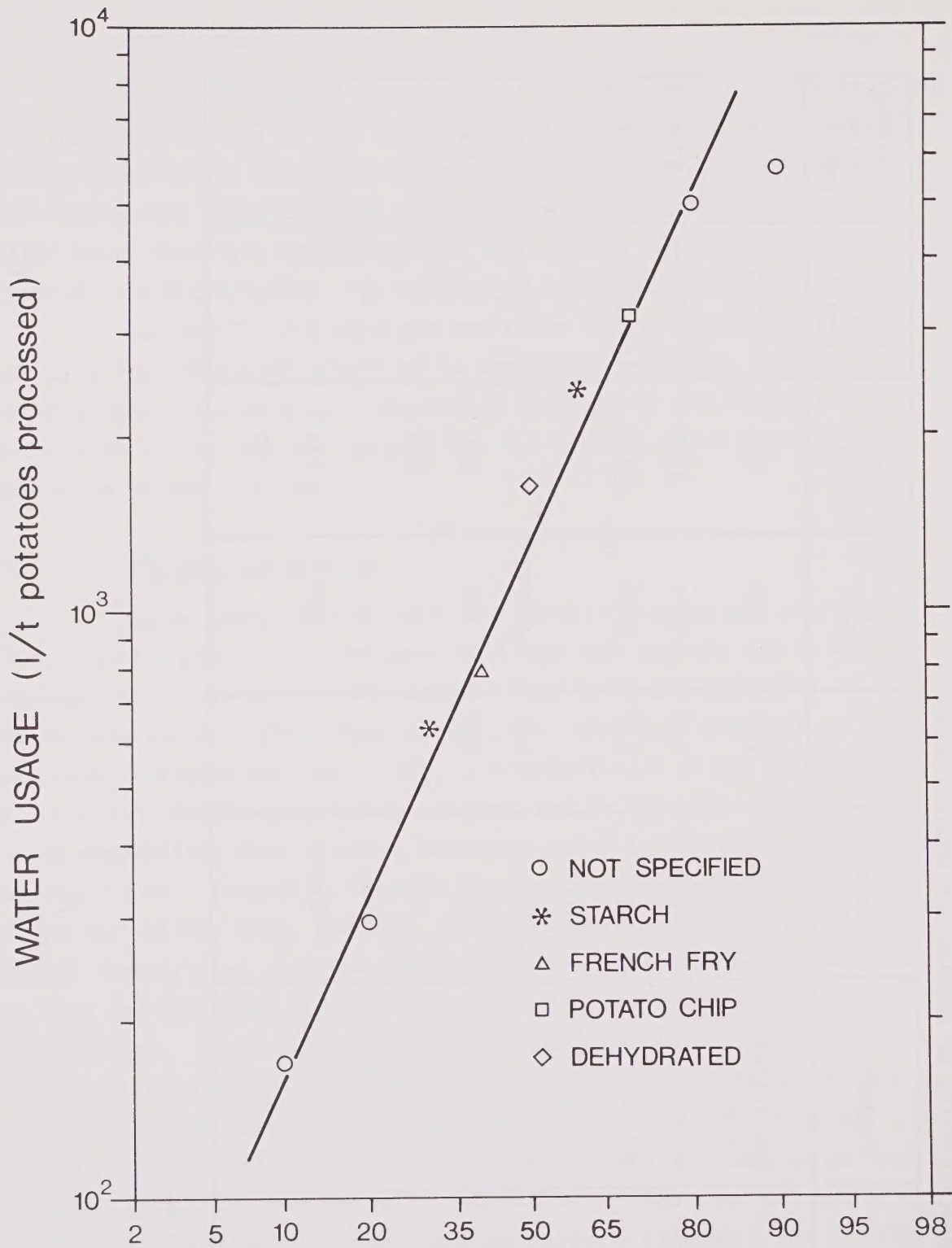


FIGURE 4. DISTRIBUTION OF WATER USAGE IN FLUMING AND WASHING OPERATIONS.

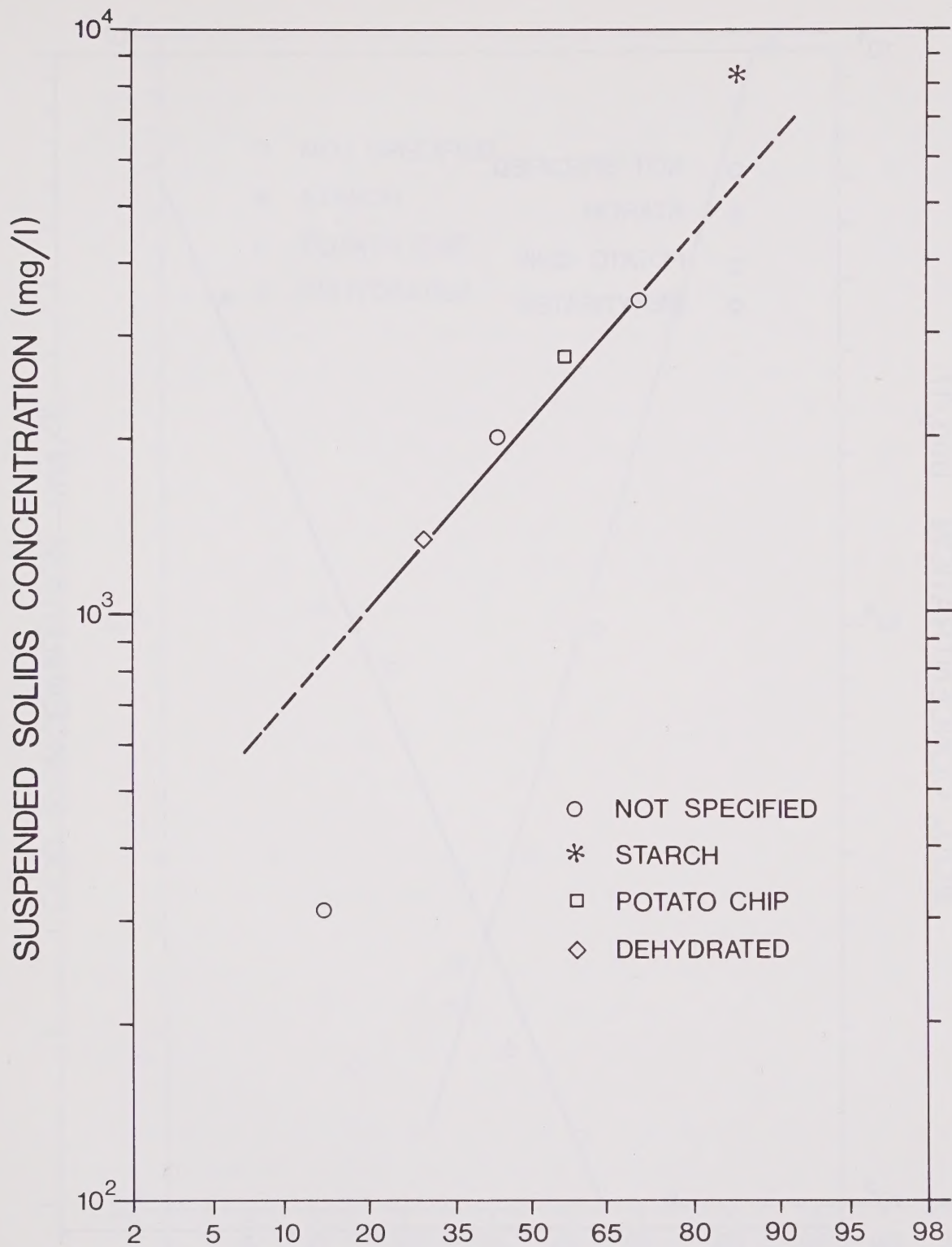


FIGURE 5. DISTRIBUTION OF SUSPENDED SOLIDS CONCENTRATIONS IN FLUMING AND WASHING WASTES

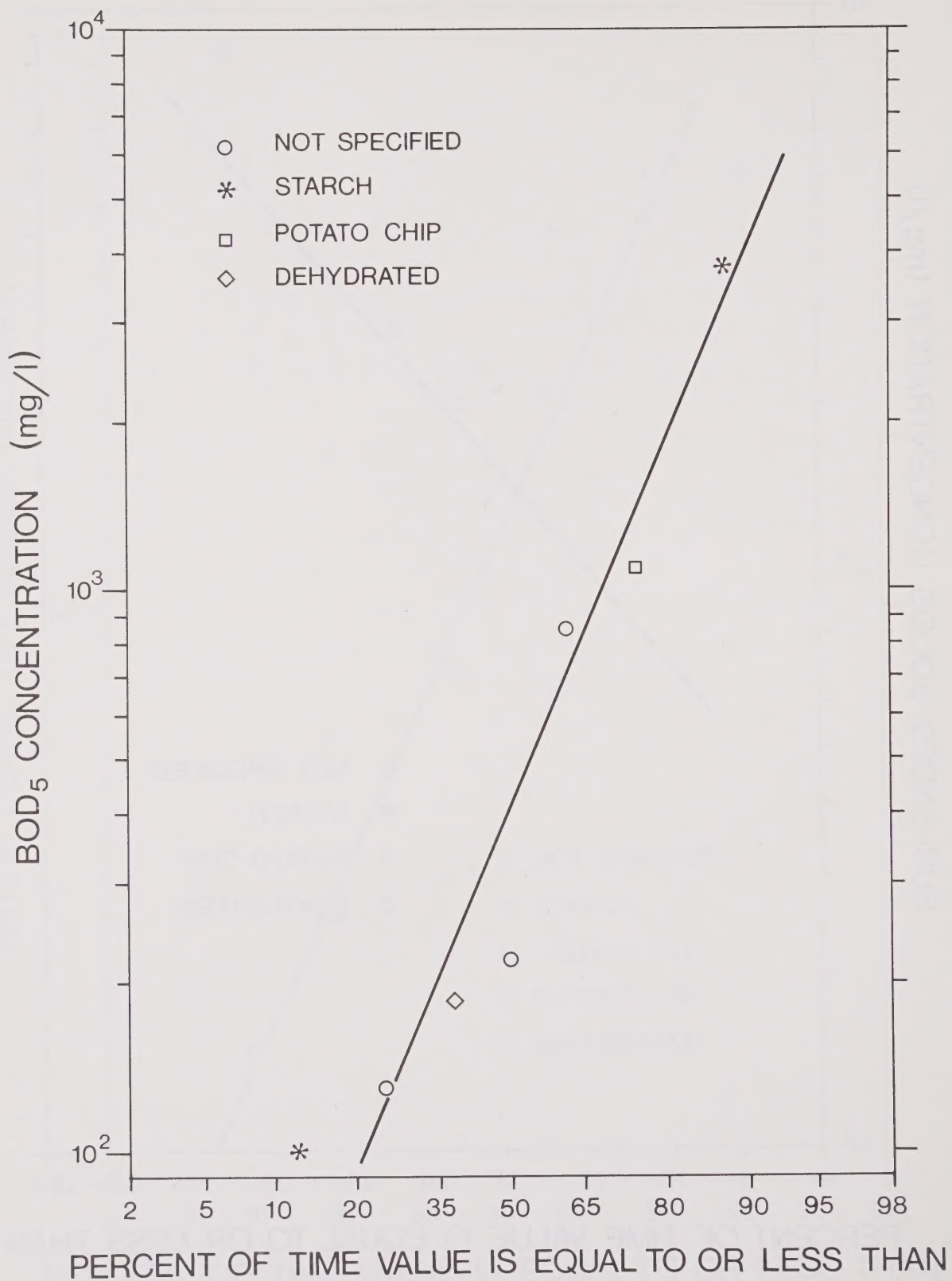
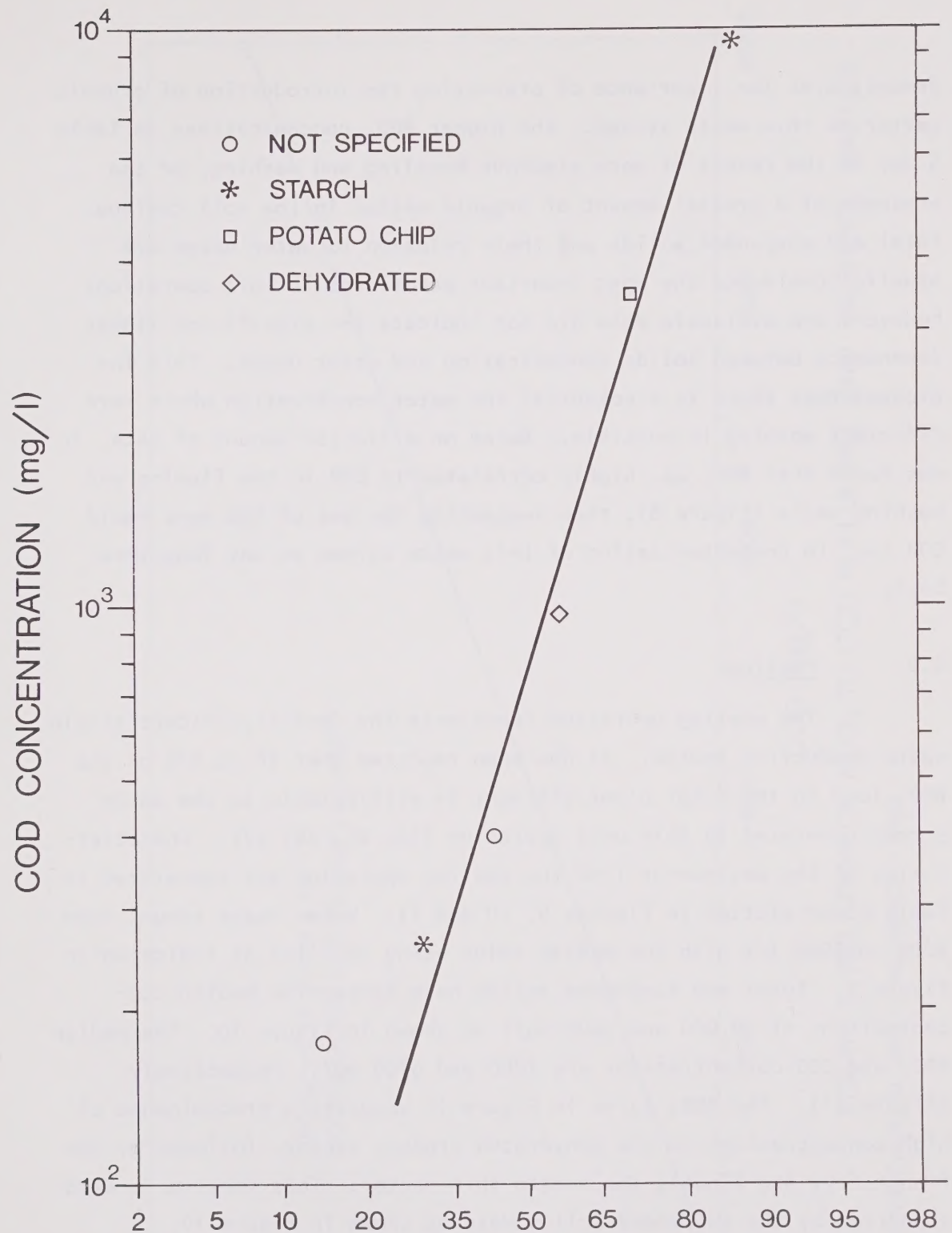


FIGURE 6. DISTRIBUTION OF BOD₅ CONCENTRATIONS IN FLUMING AND WASHING WASTES



PERCENT OF TIME VALUE IS EQUAL TO OR LESS THAN

FIGURE 7. DISTRIBUTION OF COD CONCENTRATIONS IN
FLUMING AND WASHING WASTES

demonstrates the importance of preventing the introduction of organic matter to this waste stream. The higher BOD_5 concentrations in Table 5 may be the result of more vigorous handling and washing, or the presence of a greater amount of organic matter in the soil residue. Total and suspended solids and their relation to water usage are usually considered the most important parameters in this operation; however, the available data did not indicate any significant linear dependence between solids concentration and water usage. This indicates that there is a potential for water conservation where more efficient washing is possible. Based on a limited amount of data, it was found that BOD_5 was highly correlated to COD in the fluming and washing waste (Figure 8), thus suggesting the use of the more rapid COD test in characterization of this waste stream on any long-term basis.

4.2 Peeling

The peeling operation represents the most significant single waste production source. It has been reported that 50 to 91% of the BOD_5 load in the total plant effluent is attributable to the waste stream generated in this unit operation (15, 25, 26, 27). Characteristics of the wastewater from the peeling operation are summarized in Table 6 and plotted in Figures 9, 10 and 11. Water usage ranges from 2000 to 5500 l/t with the median value being 3000 l/t as indicated in Figure 9. Total and suspended solids have respective median concentrations of 10,000 and 3600 mg/l as shown in Figure 10. The median BOD_5 and COD concentrations are 2800 and 6700 mg/l, respectively (Figure 11). The BOD_5 curve in Figure 11 suggests a predominance of high concentrations in the dehydrated product sector, followed by the french fry, and finally the potato chip sector. This ranking is also supported by the suspended solids data as shown in Figure 10.

The relationship between the BOD_5 and COD concentrations is shown in Figure 12. The high correlation suggests that COD can be used as a more convenient method for characterizing peel wastes on a routine basis. Figure 13 indicates the relationship of the BOD_5 and

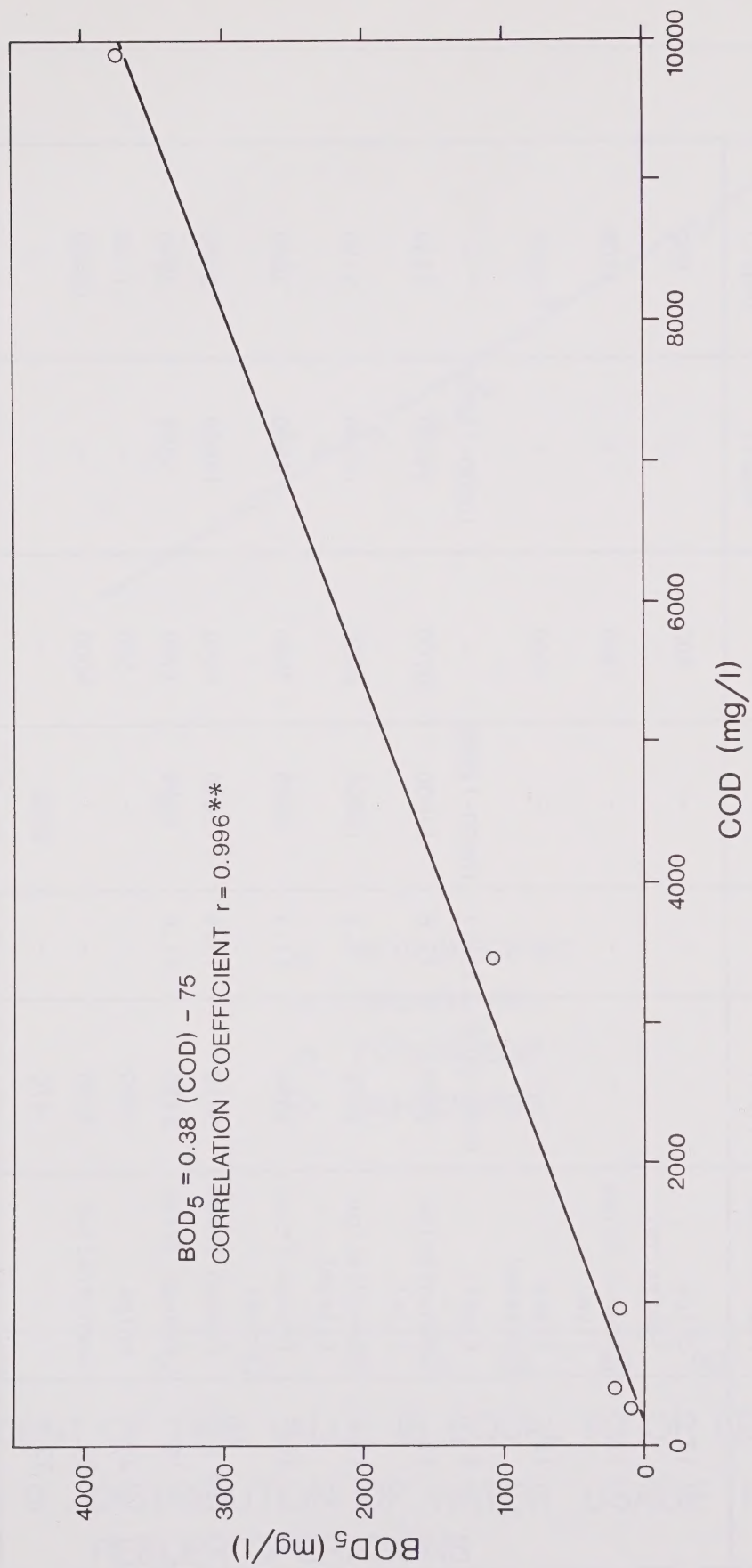


FIGURE 8. RELATION OF BOD₅ TO COD IN FLUMING AND WASHING WASTES.

** SIGNIFICANT AT 99% CONFIDENCE LEVEL

TABLE 6. CHARACTERISTICS OF PEELER WASTES

Reference	Product and Peel Method	Water Usage (l/t)	pH	COD (mg/l)	BOD ₅ (mg/l)	Total Solids (mg/l)	Suspended Solids (mg/l)
12	chips (abrasive)	-	-	-	400	-	950
12	french fries (lye)	-	-	-	1900	-	4500
12	flake (steam)	-	-	-	3000	-	3500
21	(lye)	5040-5460	12-13	10000-12000	-	10000-15000	-
19	dehydration (lye)	3000	12.6	11000	6700	19890	8330
19	dehydration (steam)	2625	5.3	10000	6250	10200	5140
28	french fries (lye)	3940	11.5	6000	3550	6880	2660
28 & 26	french fries	5010	11.5	2830	1950	14900	2480
19	french fries	2350	11.4	4940	2780	5050	3640
29	chips	1970	-	-	580	-	1120
29	dehydration	2520	-	-	4000	-	18000
22	--	670	-	6000	-	-	-

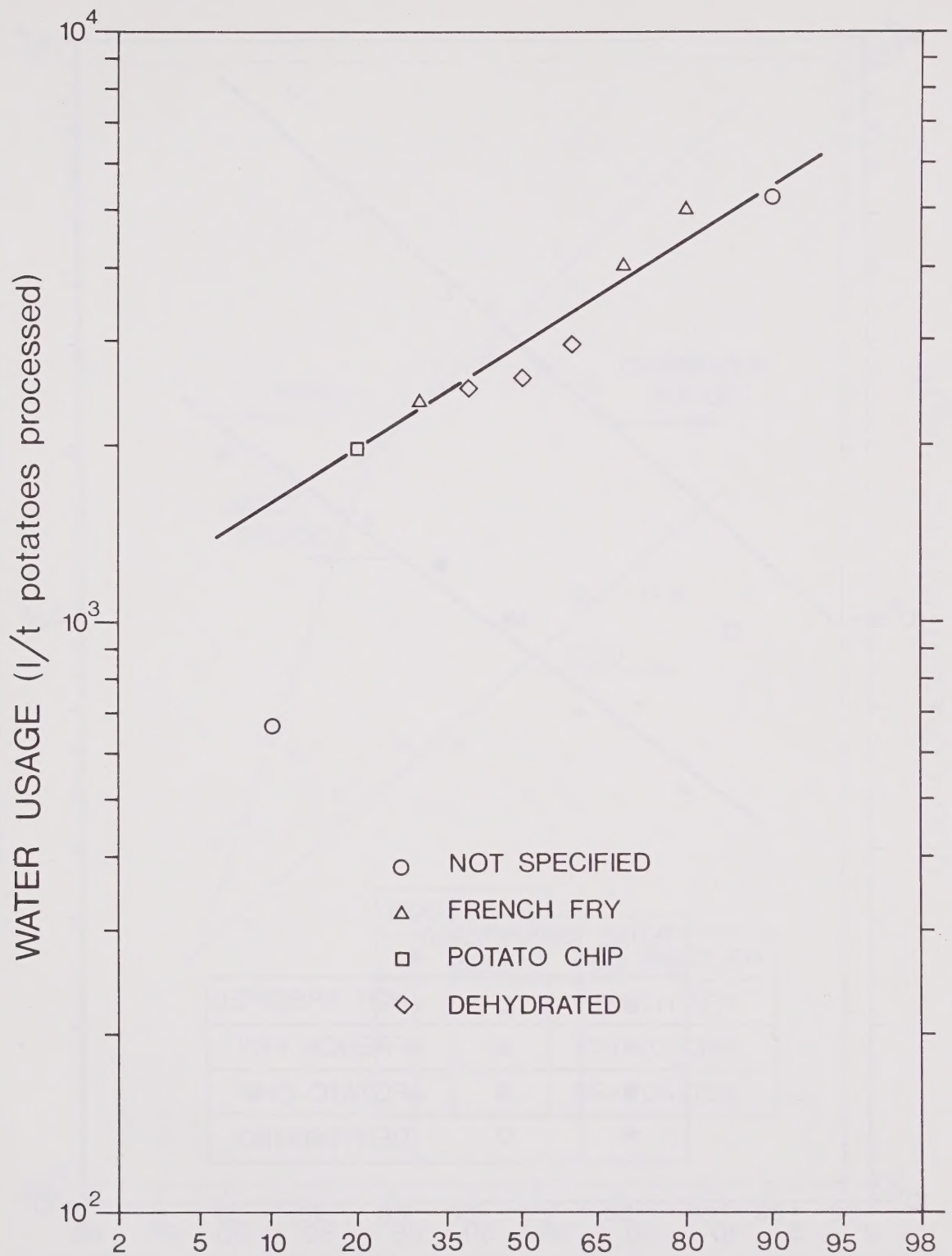


FIGURE 9 . DISTRIBUTION OF WATER USAGE FROM PEELER OPERATIONS

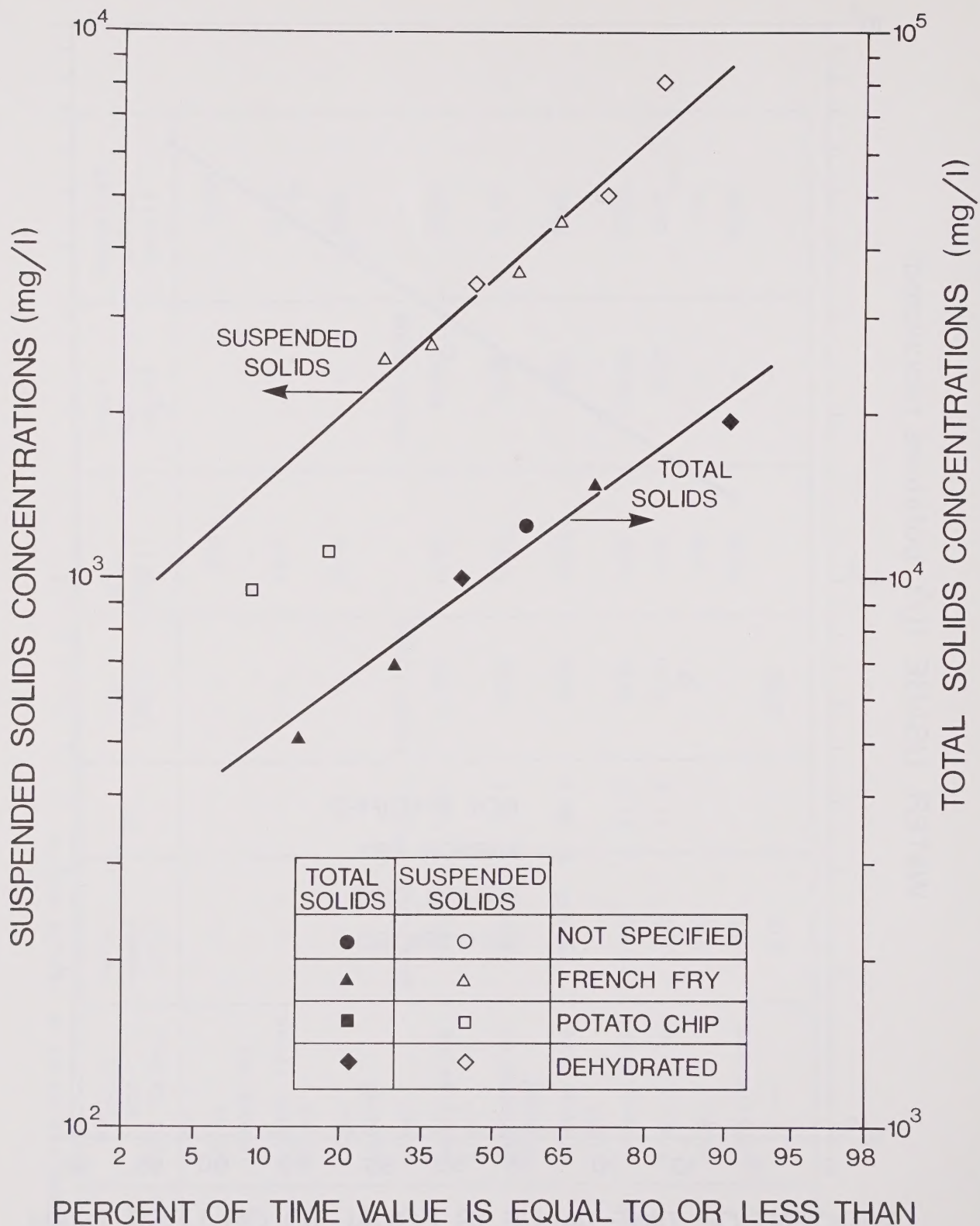


FIGURE 10. DISTRIBUTION OF TOTAL AND SUSPENDED SOLIDS IN PEELER WASTES

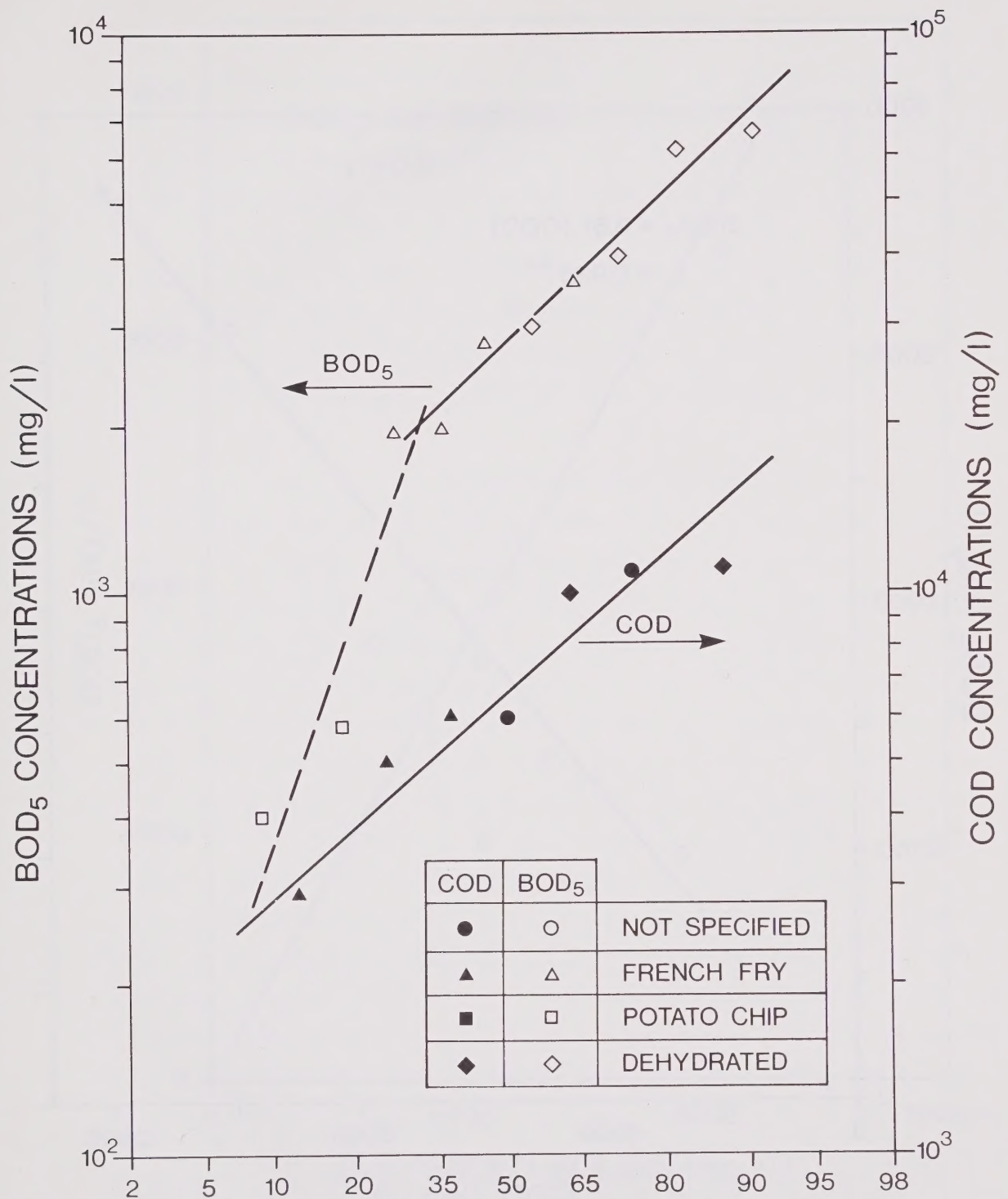


FIGURE 11. DISTRIBUTION OF BOD₅ AND COD CONCENTRATIONS IN PEELER WASTES

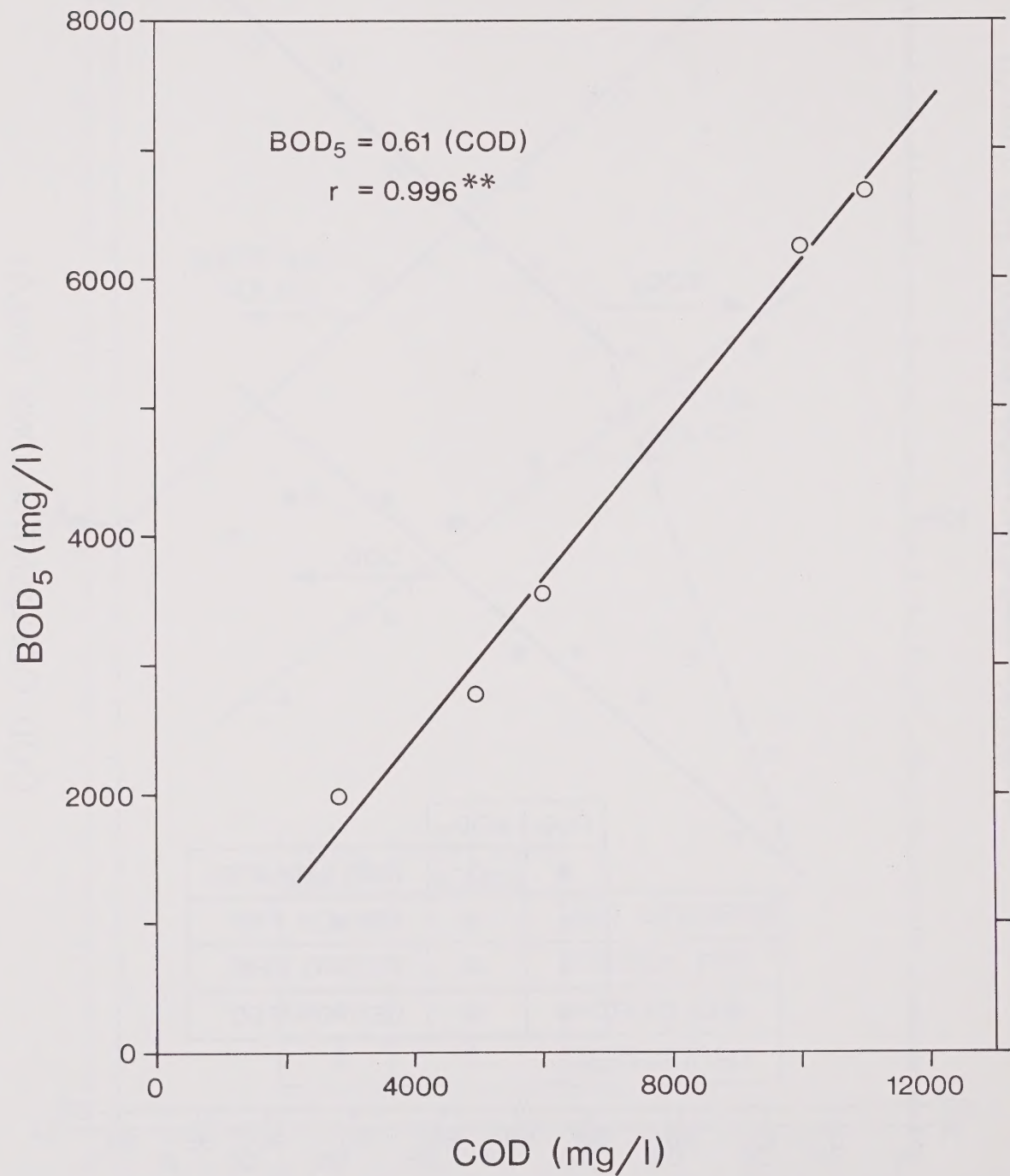


FIGURE 12. RELATION OF BOD₅ TO COD IN PEELER WASTES

** SIGNIFICANT AT 99% CONFIDENCE LEVEL

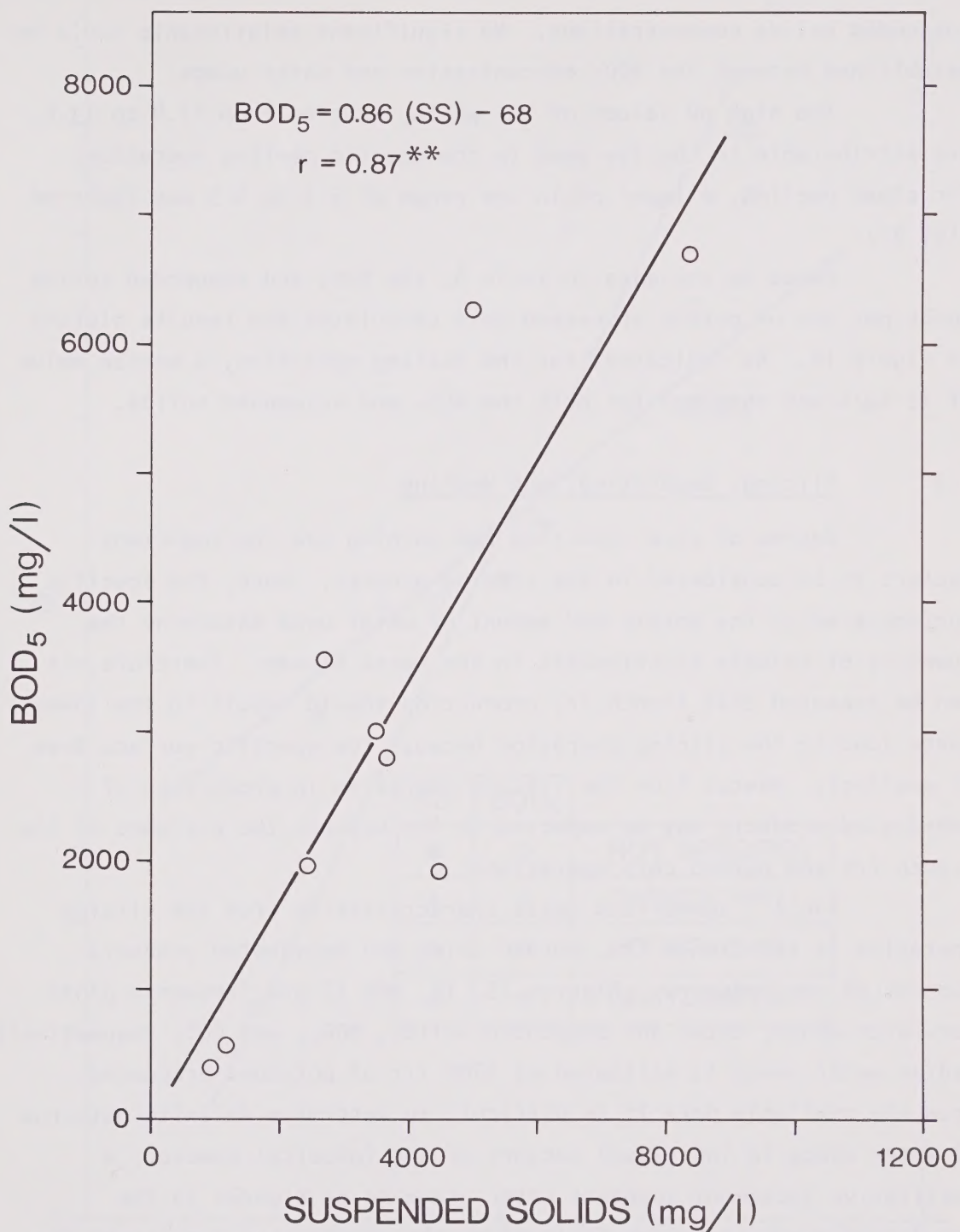


FIGURE 13. RELATION OF BOD₅ TO SUSPENDED SOLIDS
IN PEELER WASTES

** SIGNIFICANT AT 99% CONFIDENCE LEVEL

suspended solids concentrations. No significant relationship could be established between the BOD₅ concentration and water usage.

The high pH values of the waste, ranging from 11.4 to 13.0, are attributable to the lye used in the caustic peeling operation. For steam peeling, a lower pH in the range of 5.3 to 6.5 was reported (19, 21).

Based on the data in Table 6, the BOD₅ and suspended solids loads per ton of potato processed were calculated and results plotted in Figure 14. As indicated, for the peeling operation, a median value of 13 kg/t was obtained for both the BOD₅ and suspended solids.

4.3 Slicing, Separating, and Washing

Degree of size reduction and washing are the important factors to be considered in the slicing process. Here, the specific surface area of the potato and amount of water used determine the quantity of soluble constituents in the waste stream. Therefore, it can be expected that french fry production should result in the lowest waste load in the slicing operation because the specific surface area is smallest. Wastes from the slicing operation in production of dehydrated products may be expected to lie between the extremes of the french fry and potato chip operations.

Table 7 summarizes waste characteristics from the slicing operation in the french fry, potato chip, and dehydrated products sectors of the industry. Figures 15, 16, and 17 are frequency plots for water usage, total and suspended solids, BOD₅, and COD, respectively. Median water usage is estimated at 3700 l/t of potatoes processed. From the available data it is difficult to determine definite patterns of water usage in individual sectors of the industry; however, a qualitative judgement suggests water usage to be highest in the dehydrated products sector followed by the potato chip and french fry sectors. Median concentrations for BOD₅, COD, total, and suspended solids are 1500, 2000, 5300, and 1000 mg/l, respectively. As shown in Figure 16, the curve for suspended solids was divided into two components, the lower component representing the data for french fry waste, and the upper component representing the potato chip and

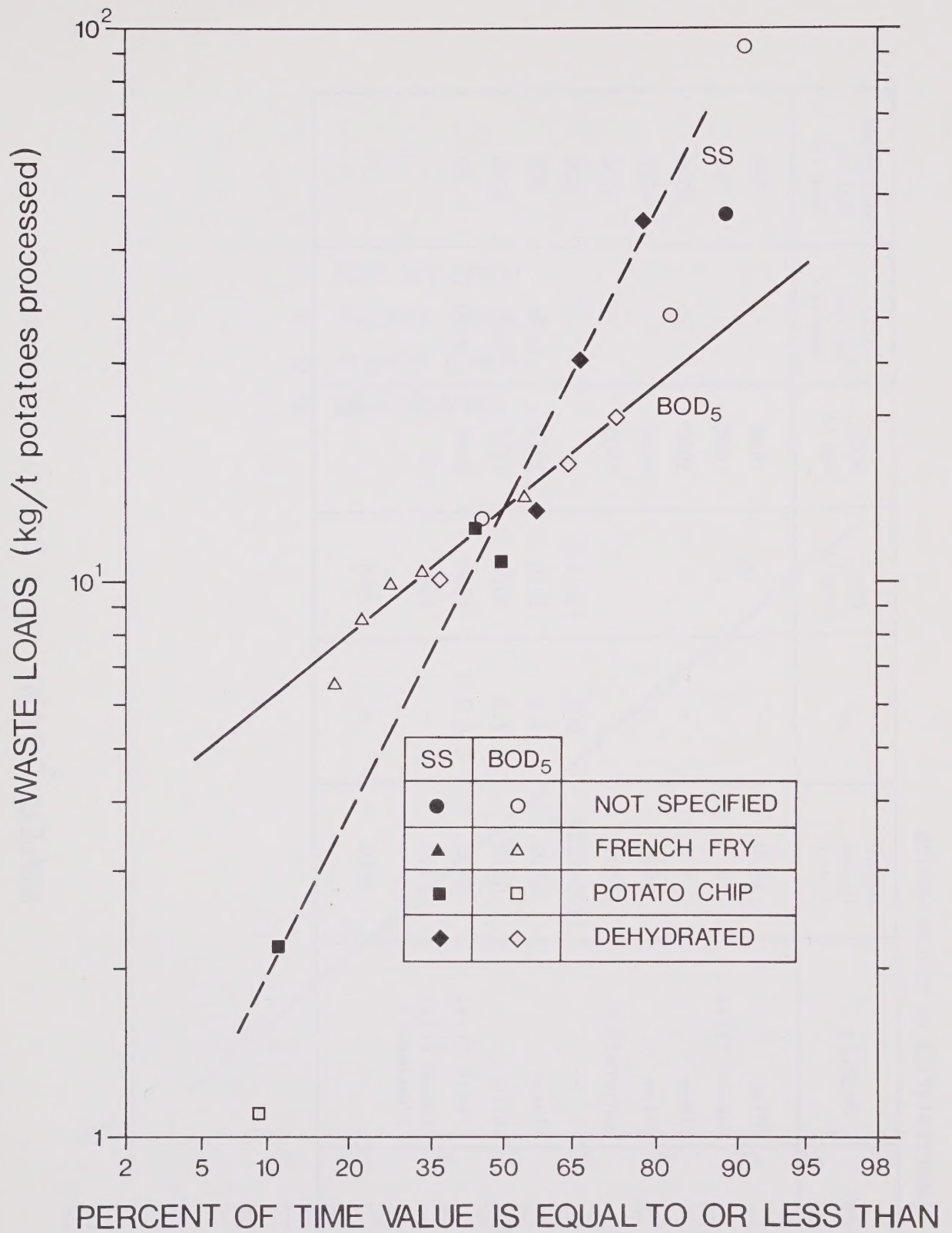


FIGURE 14. DISTRIBUTION OF SUSPENDED SOLIDS AND BOD₅ LOADS IN PEELER WASTES

TABLE 7. CHARACTERISTICS OF SLICER WASTES

Reference	Product	Water Usage (l/t)	pH	COD (mg/l)	BOD ₅ (mg/l)	Total Solids (mg/l)	Suspended Solids (mg/l)
12	chips	2690	-	-	1600	-	900
12	french fries	-	-	-	1000	-	700
12	flake	-	-	-	3000	-	2000
29	chips	2690	-	-	2020	-	4070
29	dehydration	10500	-	-	1000	-	1500
21	--	2100-2520	6.2	150-200	-	-	600
19	flake	6470	5.2	3030	2070	6780	885
19 & 30	chips	5310	7.4	4970	1440	7880	3540
28	french fries	1430	5.0-7.2	2360	2040	4360	80
25	french fries (simulated)	3330	-	2000	-	-	-
22	--	3610	-	845	-	-	-

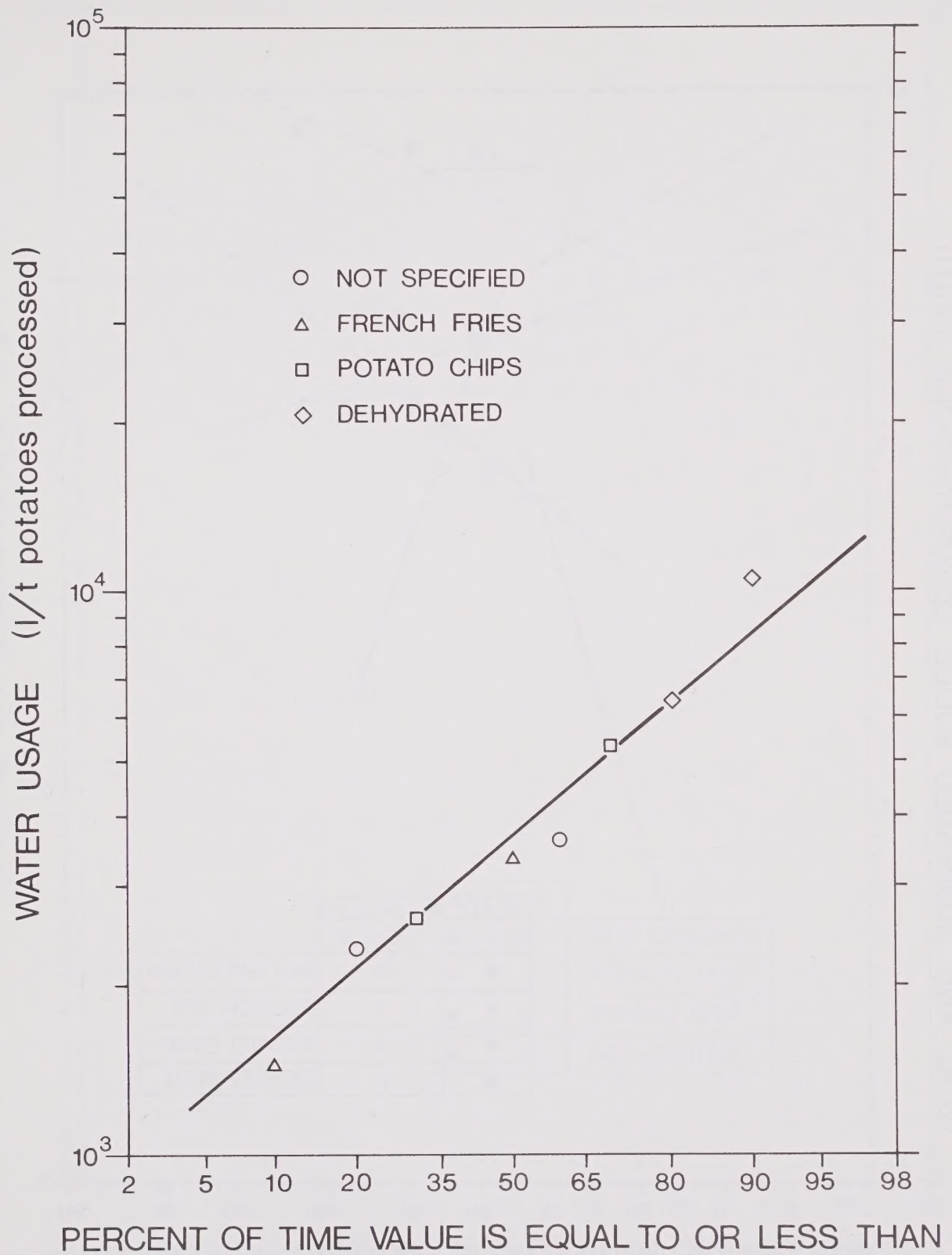


FIGURE 15. DISTRIBUTION OF WATER USAGE FROM SLICER OPERATIONS

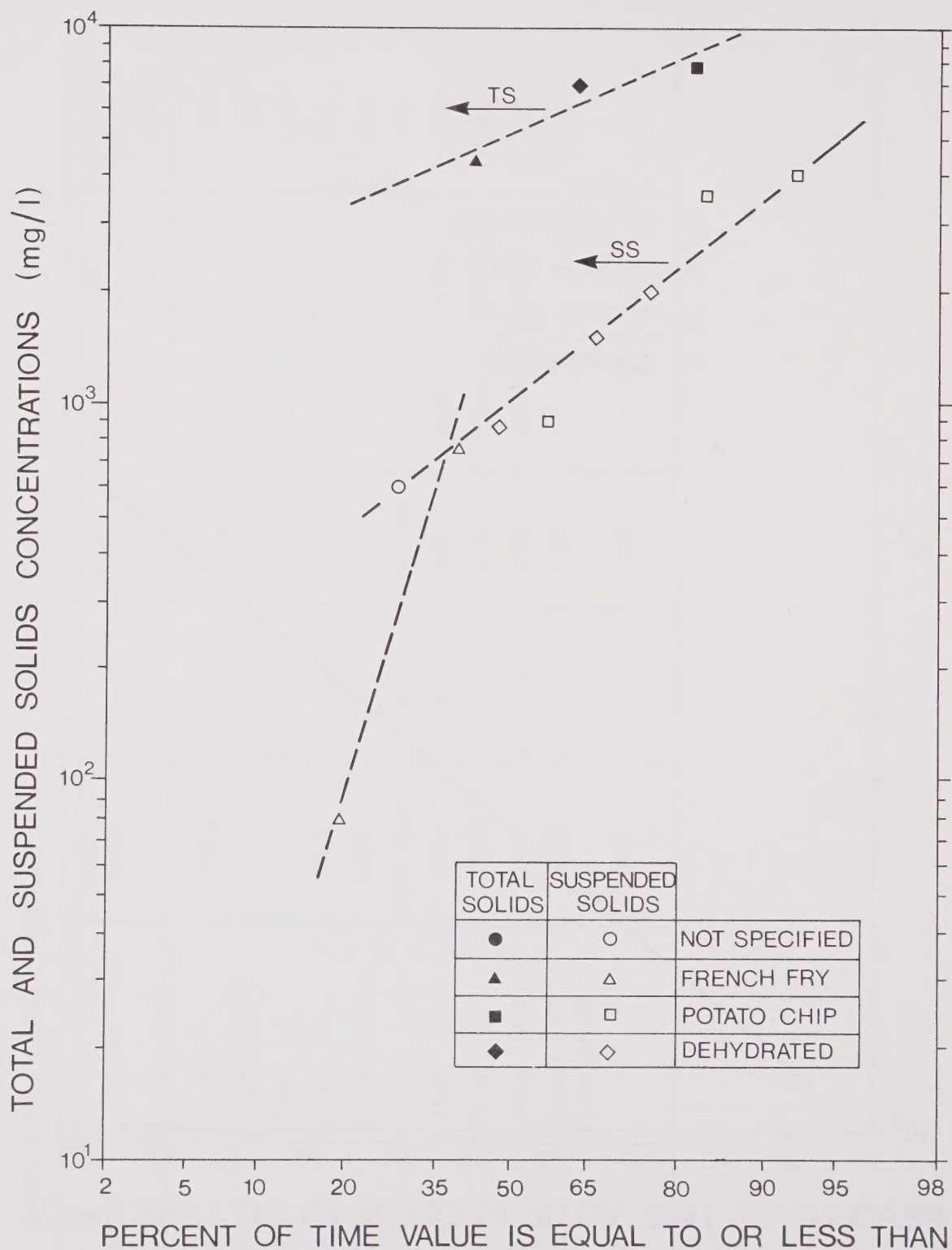


FIGURE 16. DISTRIBUTION OF TOTAL AND SUSPENDED SOLIDS IN SLICER WASTES

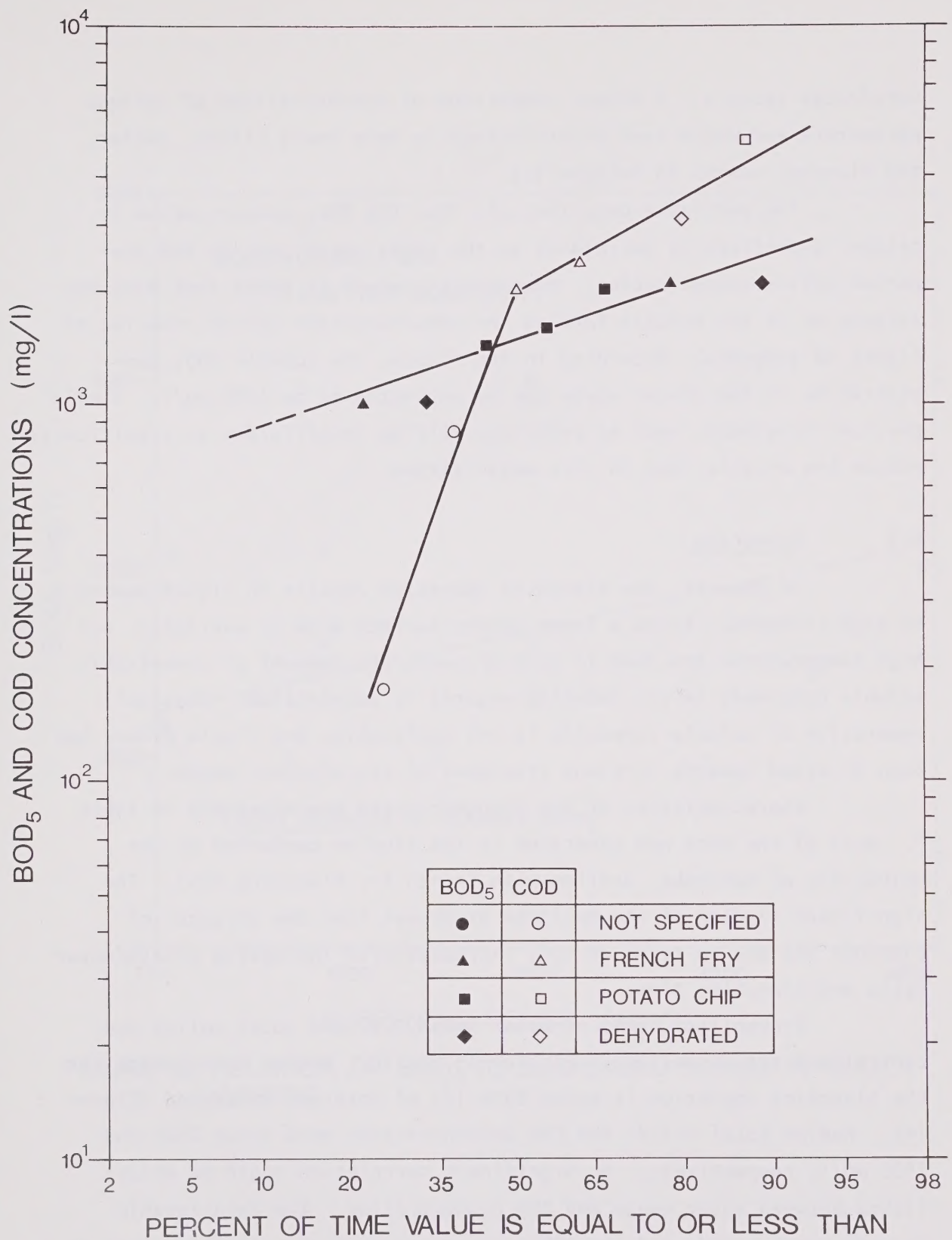


FIGURE 17. DISTRIBUTION OF BOD₅ AND COD CONCENTRATIONS IN SLICER WASTES

dehydrated sectors. A direct comparison of concentrations of various parameters and waste load contributions is made among slicer, peeler, and blancher wastes in Section 4.5.

The available data indicate that the BOD_5 concentration is neither significantly correlated to the water usage, nor to the suspended solids concentration. However, it should be noted that BOD_5 may largely be in the soluble form as the BOD_5 /suspended solids relation of Figure 18 suggests. According to the figure, the soluble BOD_5 concentration in the slicer waste can be estimated to be 1280 mg/l. Simple physical treatment, such as settling, will be insufficient to significantly reduce the organic load in this waste stream.

4.4 Blanching

In general, the blanching operation results in liquid wastes of high strength. Since a large potato surface area is available, and high temperatures are used in this process, the removal of undesirable soluble compounds (e.g., reducing sugars) is accelerated. Physical separation of soluble compounds is not applicable, and little effort has been directed towards in-plant treatment of the blancher waste.

Characteristics of the blancher waste are presented in Table 8. Most of the data was generated in the studies conducted at the University of Manitoba, dealing with french fry blanching (25). The significant finding of the Manitoba study was that the strength of blancher wastes, in terms of COD, increased with increasing potato/water ratio and blanching time.

Probability plots of water usage, COD and total solids concentrations are presented in Figures 19 and 20. Median water usage for the blanching operation is about 2900 l/t of potatoes processed (Figure 19). Median total solids and COD concentrations were about 2200 and 2400 mg/l, respectively. No significant correlation could be established between water usage and COD concentration. The relationship between total solids and the COD concentration of the blancher waste is presented in Figure 21, indicating that these two parameters are highly correlated.

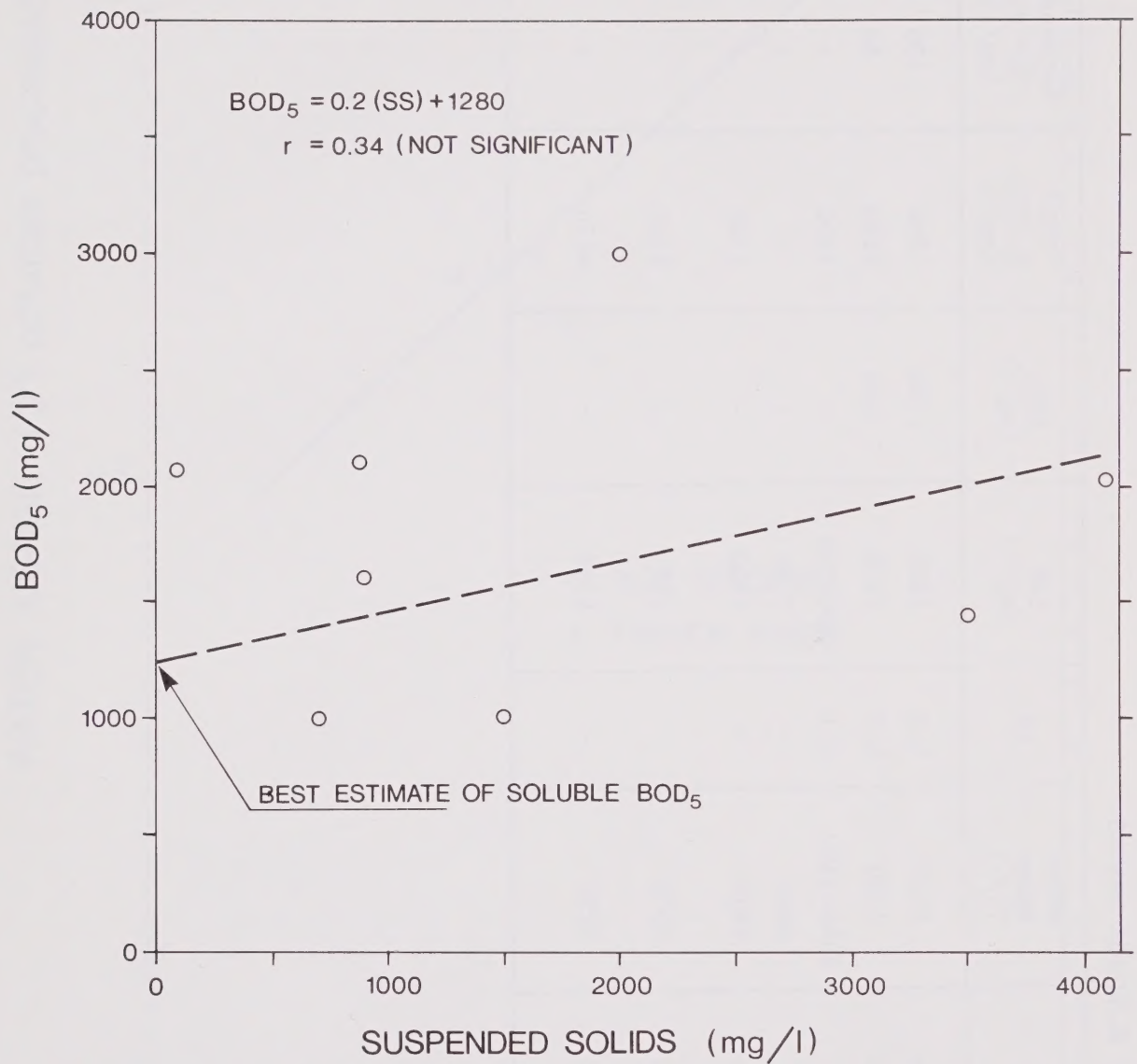


FIGURE 18. RELATION OF BOD_5 TO SUSPENDED SOLIDS IN SLICER WASTES

TABLE 8. CHARACTERISTICS OF BLANCHER WASTES

Reference	Product	Water Usage (l/t)	pH	COD (mg/l)	BOD ₅ (mg/l)	Total Solids (mg/l)	Suspended Solids (mg/l)
28	french fries	2020	5.0	1800	1380	1890	195
28	french fries	1300	4.7	1470	1020	2280	60
21	--	2940-3360	5.1	600-700	-	1600	-
22	--	4620	-	7300	-	-	-
25	french fries (simulated)	6670	-	1980	-	1740	-
25	french fries (simulated)	3330	-	3590	-	3700	-
25	french fries (simulated)	2220	-	4910	-	4670	-

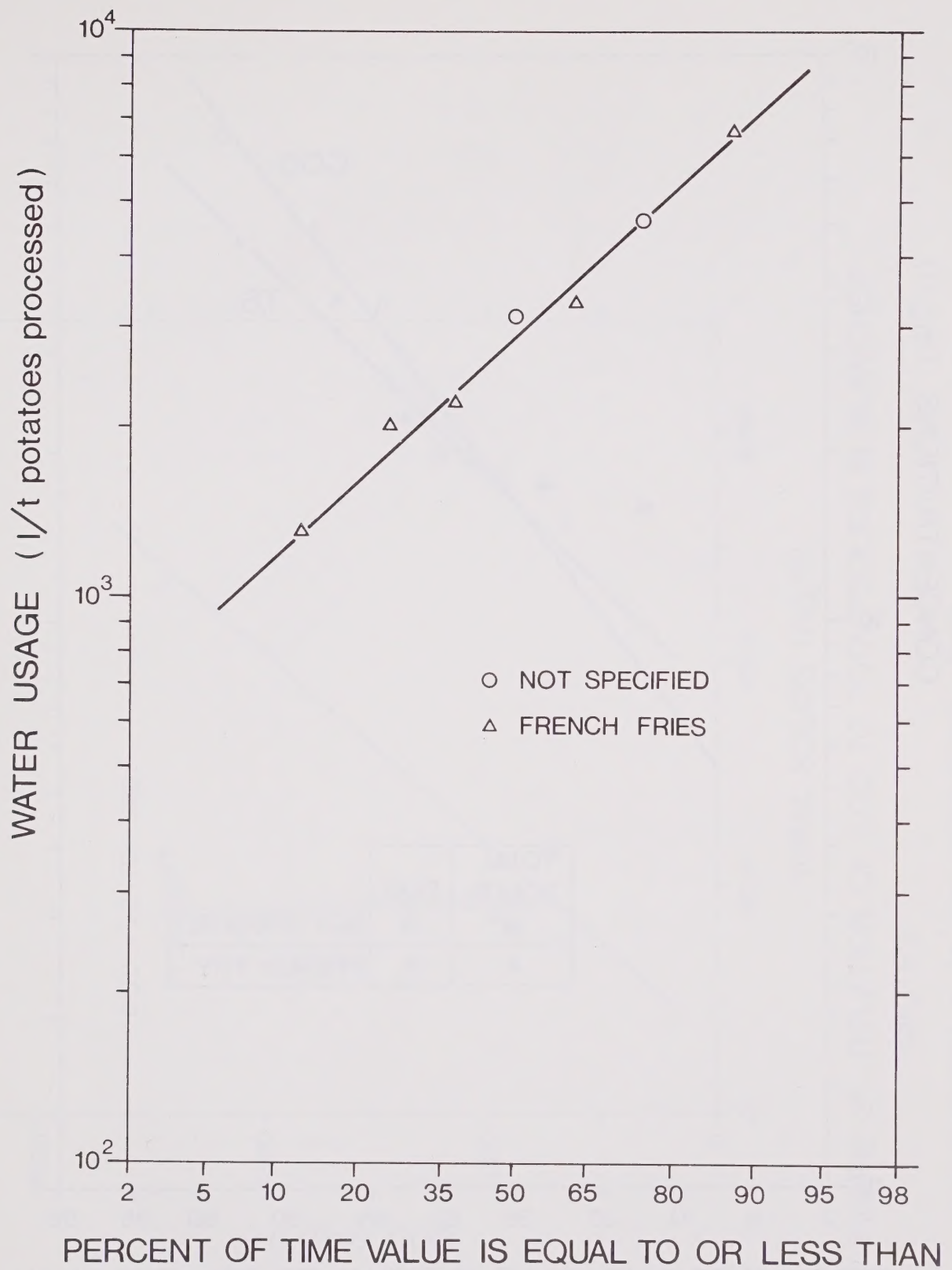


FIGURE 19. DISTRIBUTION OF WATER USAGE FROM
BLANCHER OPERATIONS

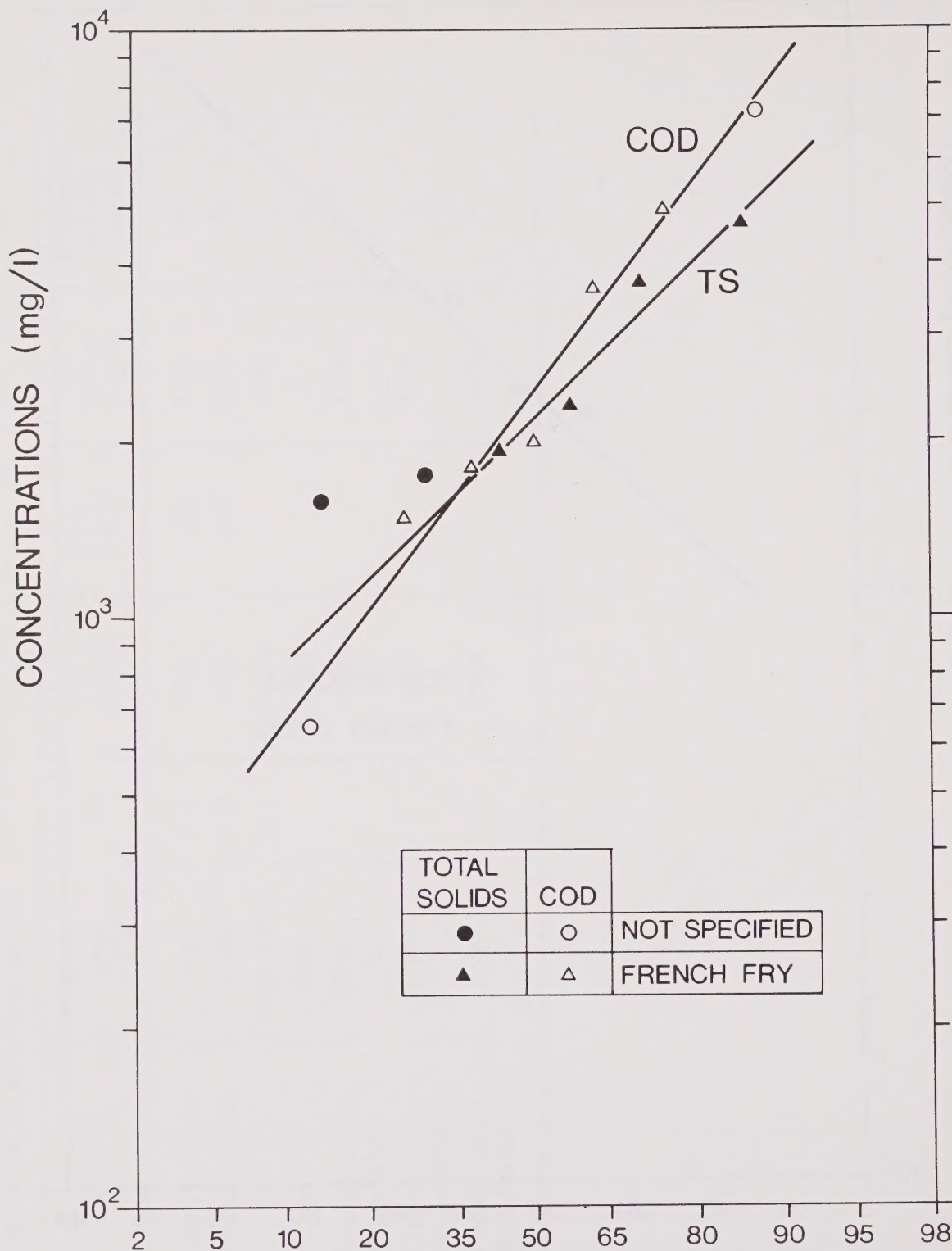


FIGURE 20. DISTRIBUTION OF COD AND TOTAL SOLIDS CONCENTRATIONS IN BLANCHER WASTES

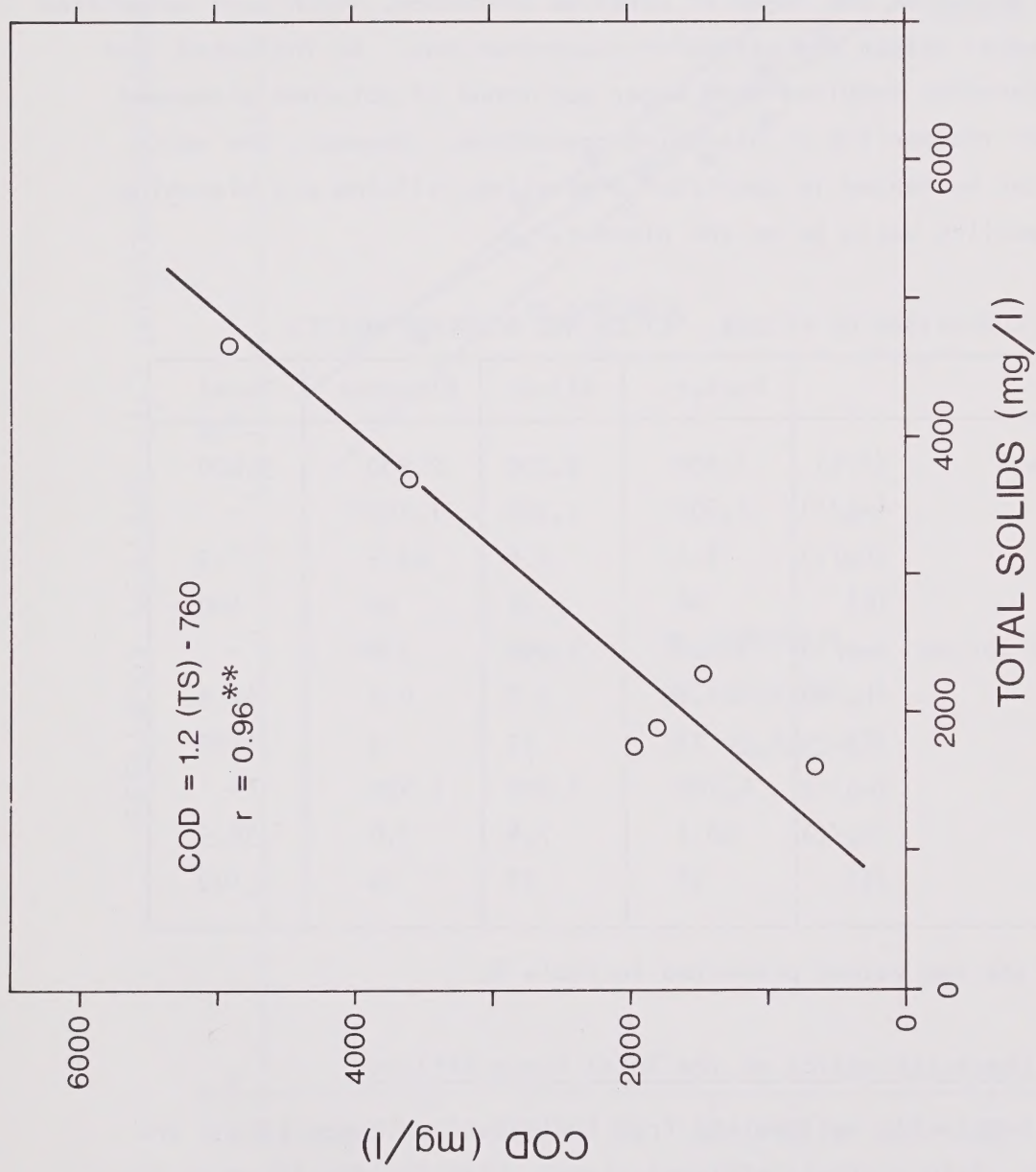


FIGURE 21. RELATION OF COD TO TOTAL SOLIDS IN BLANCHER WASTES

** SIGNIFICANT AT 99% CONFIDENCE LEVEL

4.5 Comparison of Peeler, Slicer and Blancher Wastes

For comparison, three important parameters (water usage, BOD₅ and suspended solids concentrations) of the peeler, slicer and blancher wastes are plotted in Figures 22, 23 and 24. Median values taken from these figures are summarized in Table 9. Also presented are median values in kilograms per tonne of potatoes processed, which were calculated based on water usages and parameter concentrations. As indicated, the slicing operation requires more water per tonne of potatoes processed than either the peeling or blanching operations. However, the waste strength can be ranked in the order of peeling, slicing and blanching with the peeling waste being the highest.

TABLE 9. COMPARISON OF PEELER, SLICER AND BLANCHER WASTES

		Peeler	Slicer	Blancher	Total
Water Usage	(l/t)	3,000	3,700	2,900	9,600
BOD ₅	(mg/l)	2,800	1,500	1,200*	-
	(kg/t)	8.4	5.6	3.5	17.5
	(%)	48	32	20	100
Suspended Solids	(mg/l)	3,600	1,000	130*	-
	(kg/t)	10.8	3.7	0.4	14.9
	(%)	72	25	3	100
COD	(mg/l)	6,700	2,000	2,400	-
	(kg/t)	20.1	7.4	7.0	34.5
	(%)	58	22	20	100

* Mean of the two values presented in Table 8.

4.6 Characterization of the Total Plant Effluent

Eventually wastewaters from individual unit operations are combined to yield a single effluent stream which is identified as the total plant effluent in this report. In-plant reduction of waste loads has been demonstrated to substantially reduce the effluent volume and strength; however, little information is available as to

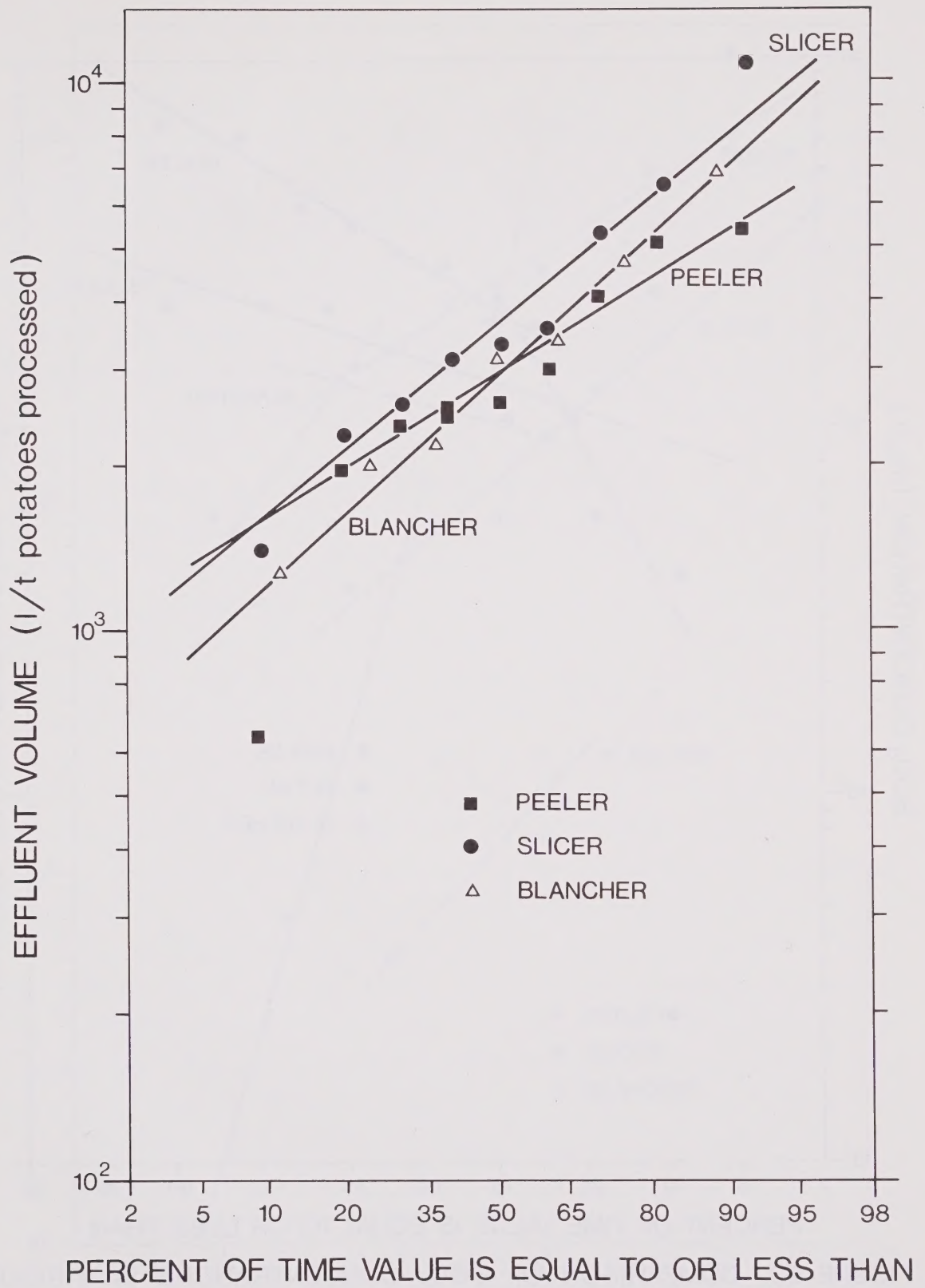


FIGURE 22. COMPARISON OF WATER USAGES IN VARIOUS UNIT OPERATIONS

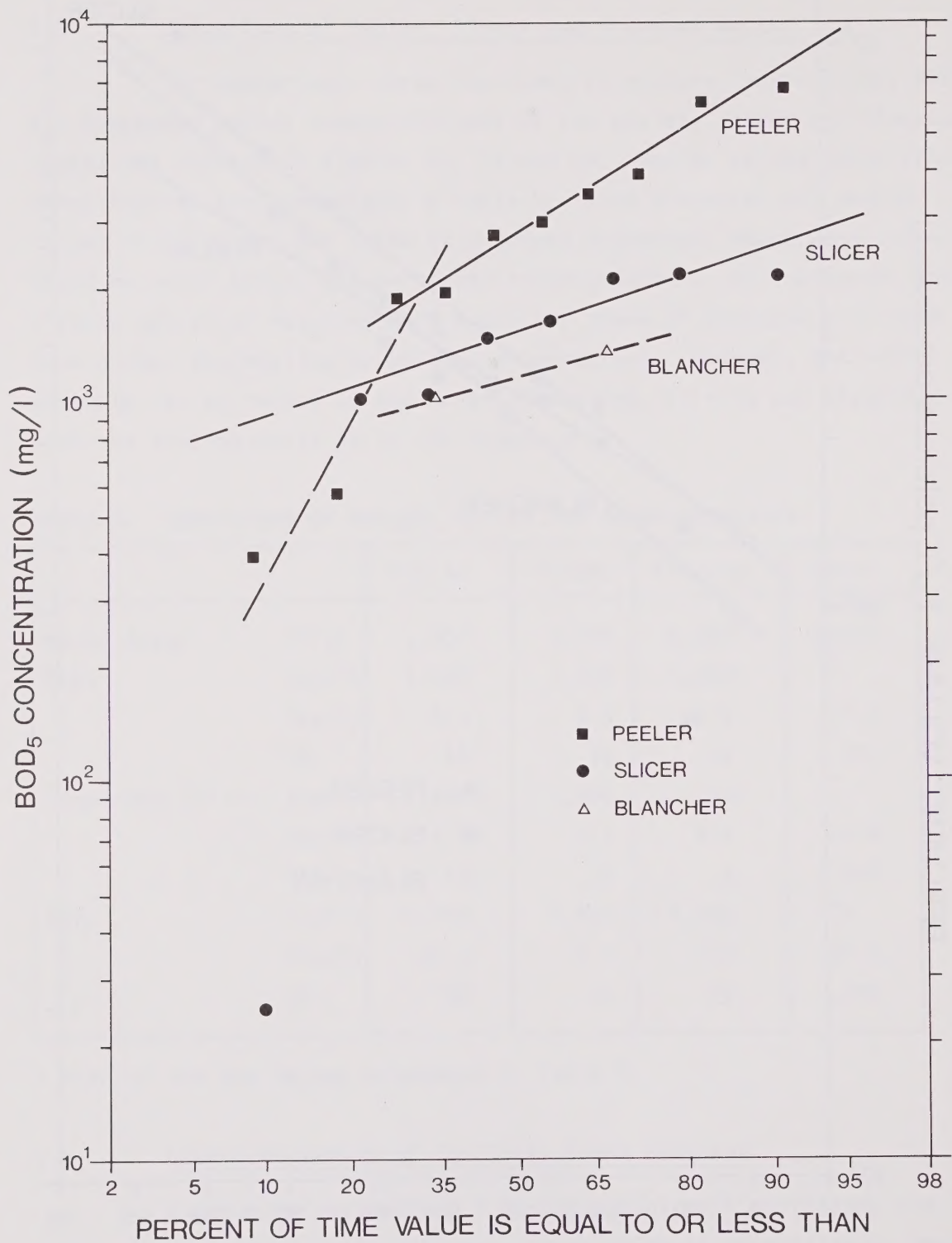


FIGURE 23. COMPARISON OF BOD₅ CONCENTRATIONS IN VARIOUS UNIT OPERATIONS

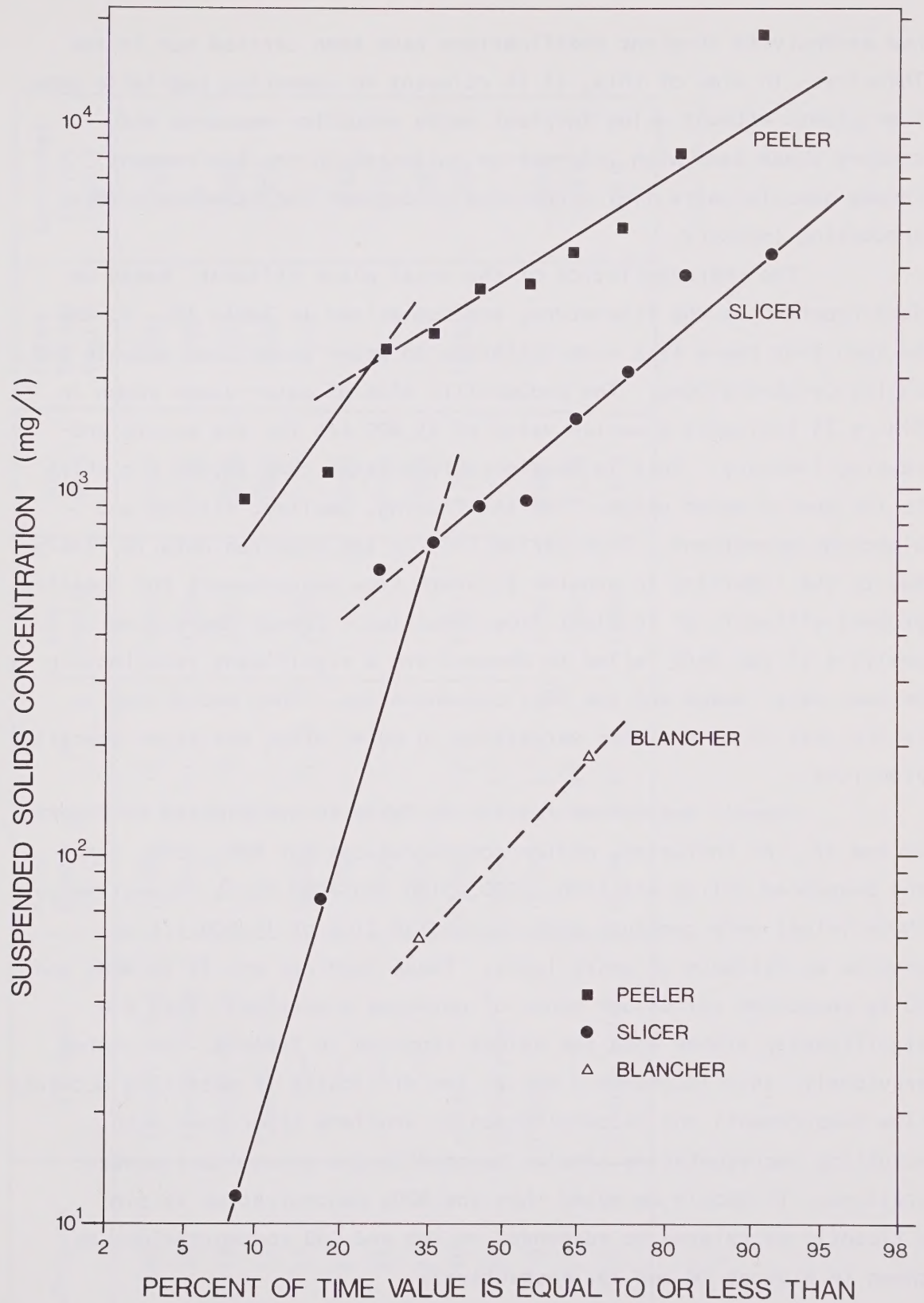


FIGURE 24. COMPARISON OF SUSPENDED SOLIDS CONCENTRATIONS IN VARIOUS UNIT OPERATIONS

how extensively in-plant modifications have been carried out in the industry. In view of this, it is relevant to summarize available data from plants without using in-plant waste reduction measures and compare these data with information collected in the Environment Canada questionnaire (10) circulated throughout the Canadian potato processing industry.

The characteristics of the total plant effluent, based on data reported in the literature, are summarized in Table 10. It can be seen that there is a wide variation in water usage, and organic and solids concentrations. The probability plot of water usage shown in Figure 25 indicates a median value of 15,000 l/t for the potato processing industry. This is considerably greater than 10,900 l/t which is the sum of water usages from the fluming, peeling, slicing and blanching operations. This variability in the reported data is likely due to the inability to provide accurate flow measurements for specific process effluents or in-plant flow reduction. Linear regression analysis of the data failed to demonstrate a significant relationship between water usage and the BOD₅ concentration. This would tend to verify that there are wide variations in water usage and plant operating practices.

Organic and solids results in Table 10 are plotted in Figures 26 and 27. As indicated, median concentrations for BOD₅, COD, total and suspended solids are 1800, 3500, 5100 and 2000 mg/l, respectively. These values were combined with the median flow of 15,000 l/t to provide an estimate of waste loads. These loadings are 27 kg BOD₅ and 30 kg suspended solids per tonne of potatoes processed. They are significantly higher than the values reported in Table 9. As stated previously, this is probably due to the difficulty in obtaining accurate flow measurements and is complicated by problems associated with acquiring representative samples to predict the contaminant concentrations. It should be noted that the BOD₅ concentration is significantly correlated to suspended solids and COD concentrations as shown in Figures 28 and 29, respectively.

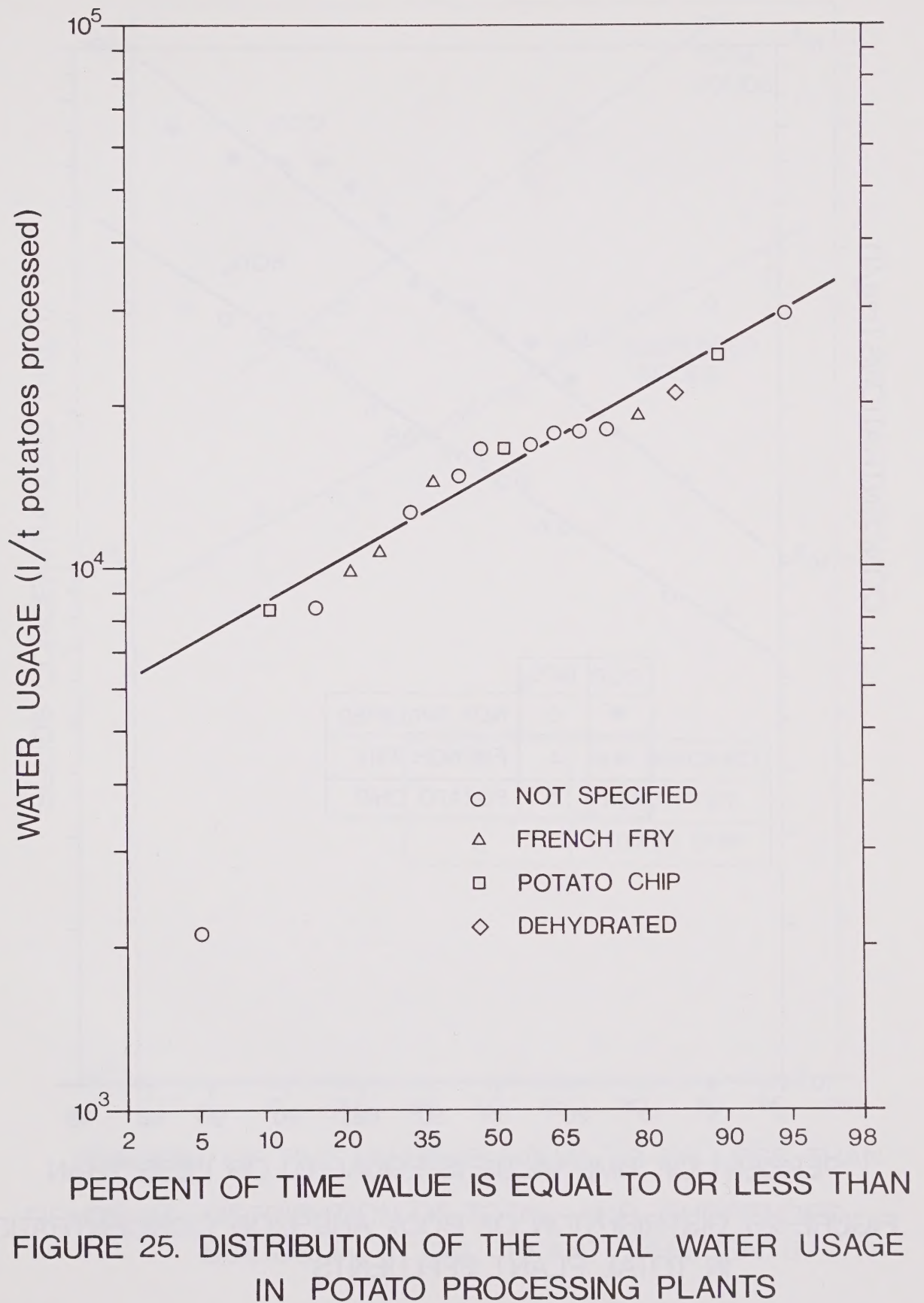
TABLE 10. CHARACTERISTICS OF TOTAL PLANT EFFLUENTS

Reference	Product	Water Usage (l/t)	pH	COD (mg/l)	BOD ₅ (mg/l)	Total Solids (mg/l)	Suspended Solids (mg/l)
28	french fries	10580	11.5	3500	2460	4890	1750
28	french fries	9700	11.1	1790	1150	8100	-
12	french fries	-	6.1	3150	2250	2950	1300
12	french fries	-	-	-	1600	3080	1320
21	--	16485	11-12	2250	-	4000	-
31	--	12600	-	-	3160	-	3160
31	--	2100	-	-	1170	-	2150
31	--	29400	-	-	860	-	990
19	chips	9400	7.4	4700	1750	10960	3580
32	dehydrated	20160	11.0	-	-	-	-
18	frozen	18900	11.0	2700	2000	-	2600
18	--	-	11.1	3300	1750	-	2064
13	french fries	24700	12.0	2720	1800	-	2010

Cont'd.... /

TABLE 10. (CONT'D). CHARACTERISTICS OF TOTAL PLANT EFFLUENTS

Reference	Product	Water Usage (l/t)	pH	COD (mg/l)	BOD ₅ (mg/l)	Total Solids (mg/l)	Suspended Solids (mg/l)
13	french fries	-	-	-	1170	-	1345
33	--	14700	7.3	-	-	-	-
20	french fries	-	7.0	-	1605	-	-
20	french fries	-	7.0	-	800	-	-
20	french fries	-	7.0	1455	-	-	-
34	--	-	-	-	-	-	2000
35 & 30	chips	16710	-	-	880	5510	-
5	--	14280	-	-	1660	-	1870
36 & 37	--	17640	11.3	5990	2570	-	3140
37	--	17640	-	-	1430	-	1710
37	--	-	11.3	5390	2730	-	2320
38	--	-	11.3	6140	2790	6440	2730
22	--	16800	-	6000	-	-	-
39	--	8400	-	-	3000	-	3000
26	--	17680	-	-	1450	-	1740
40	--	-	11.0	6475	3150	5350	2690



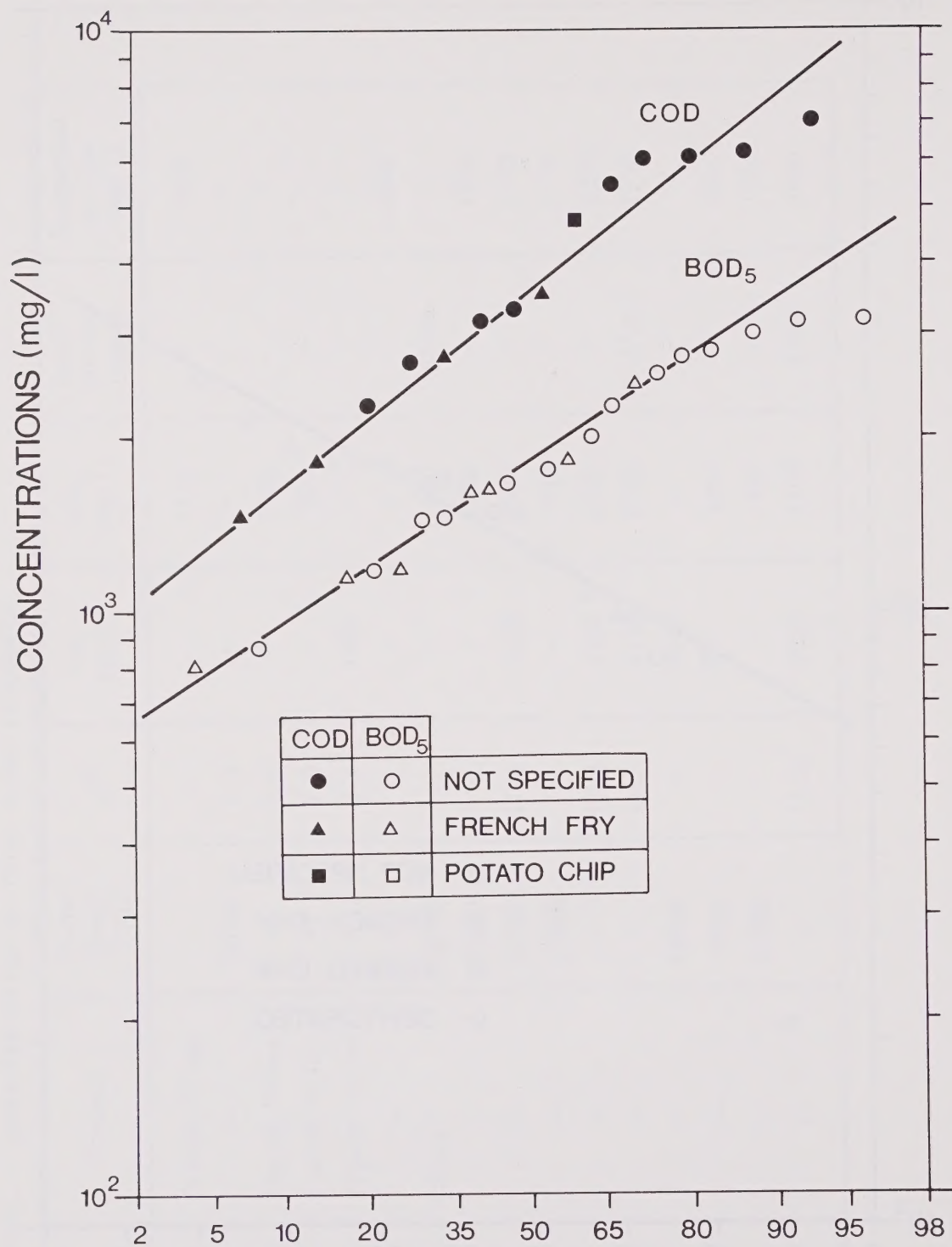


FIGURE 26. DISTRIBUTION OF BOD₅ AND COD CONCENTRATIONS
IN TOTAL PLANT EFFLUENTS

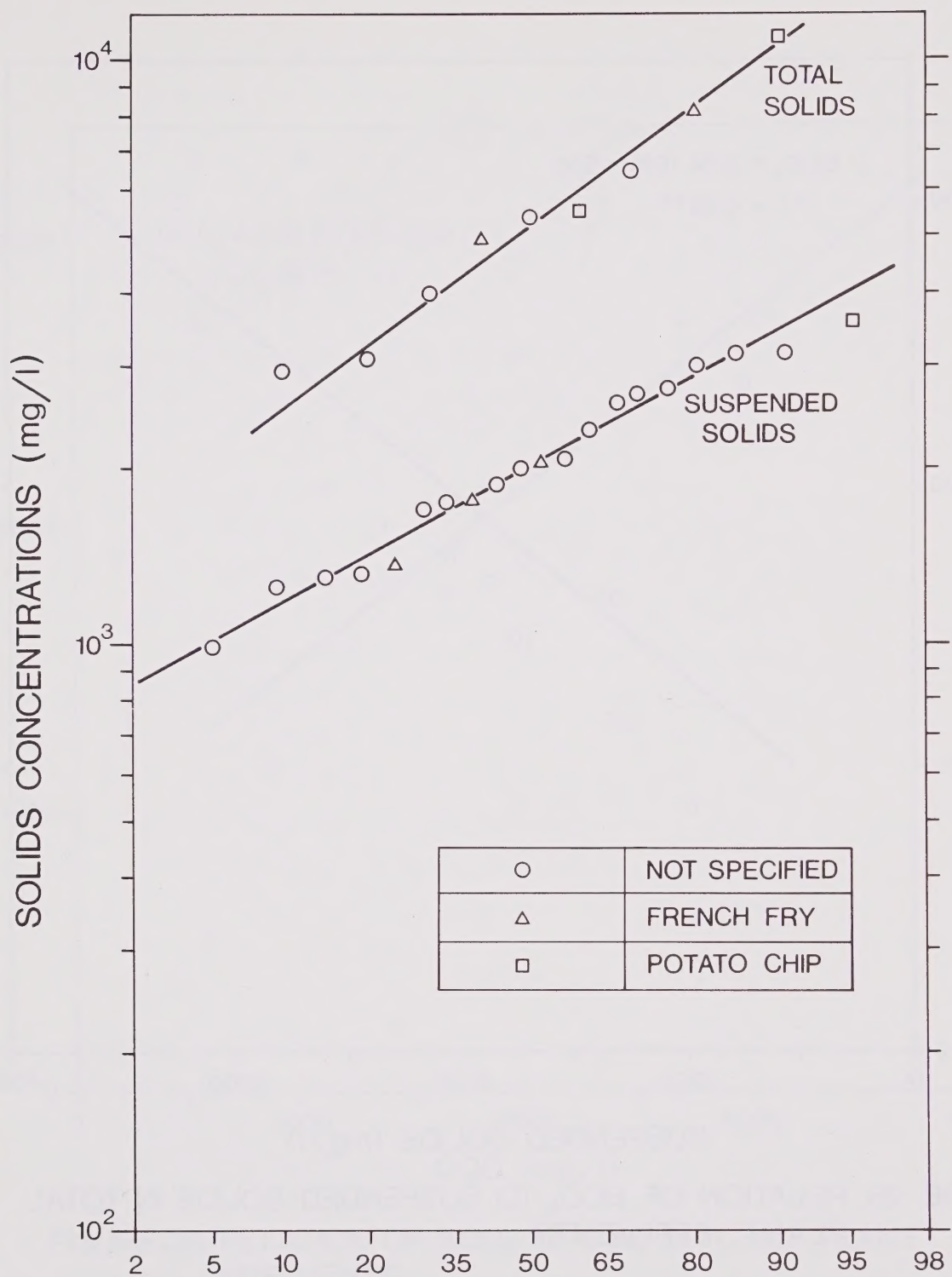


FIGURE 27. DISTRIBUTION OF TOTAL AND SUSPENDED SOLIDS IN TOTAL PLANT EFFLUENTS

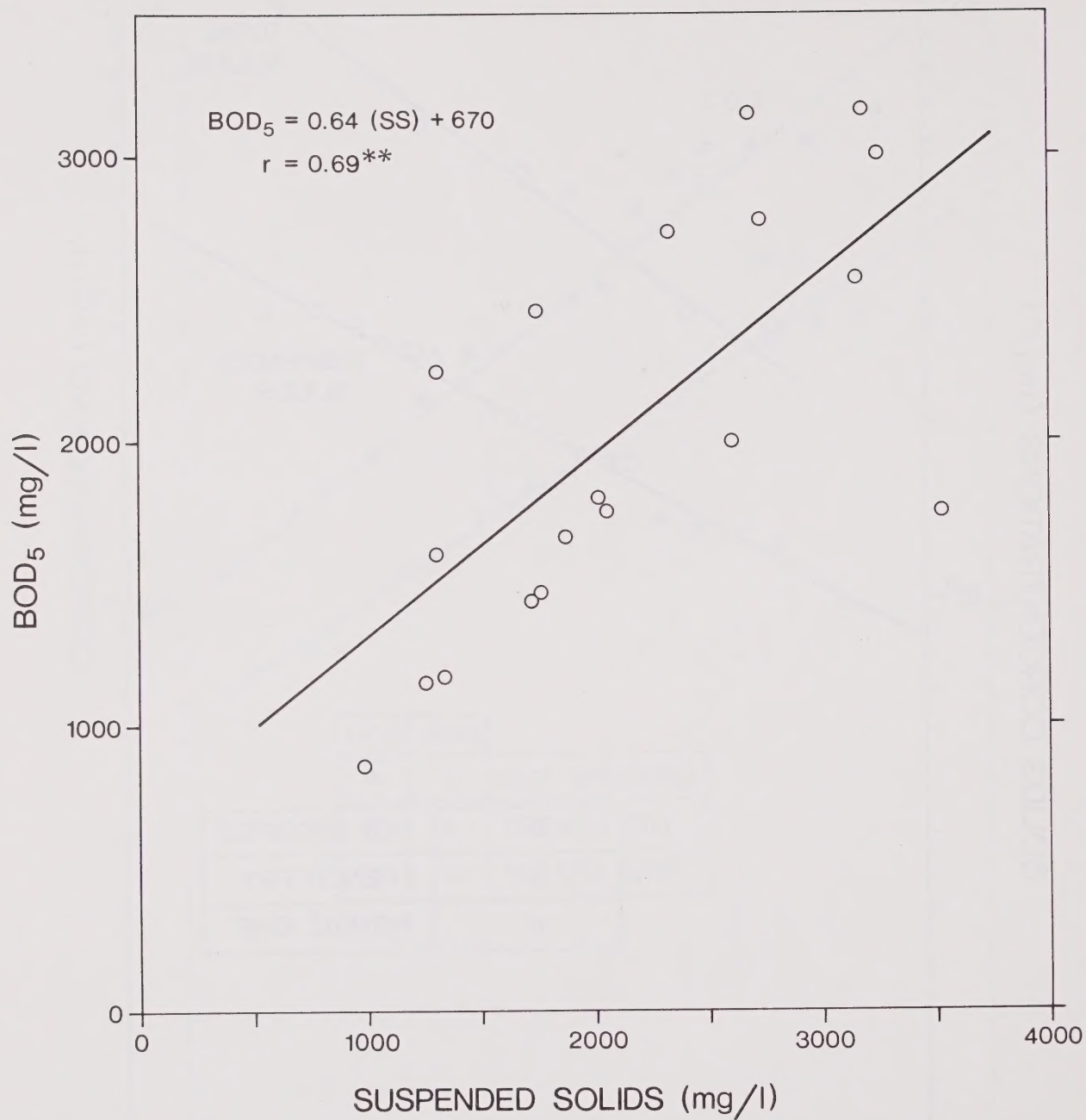


FIGURE 28. RELATION OF BOD₅ TO SUSPENDED SOLIDS IN TOTAL PLANT EFFLUENTS

** SIGNIFICANT AT 99% CONFIDENCE LEVEL

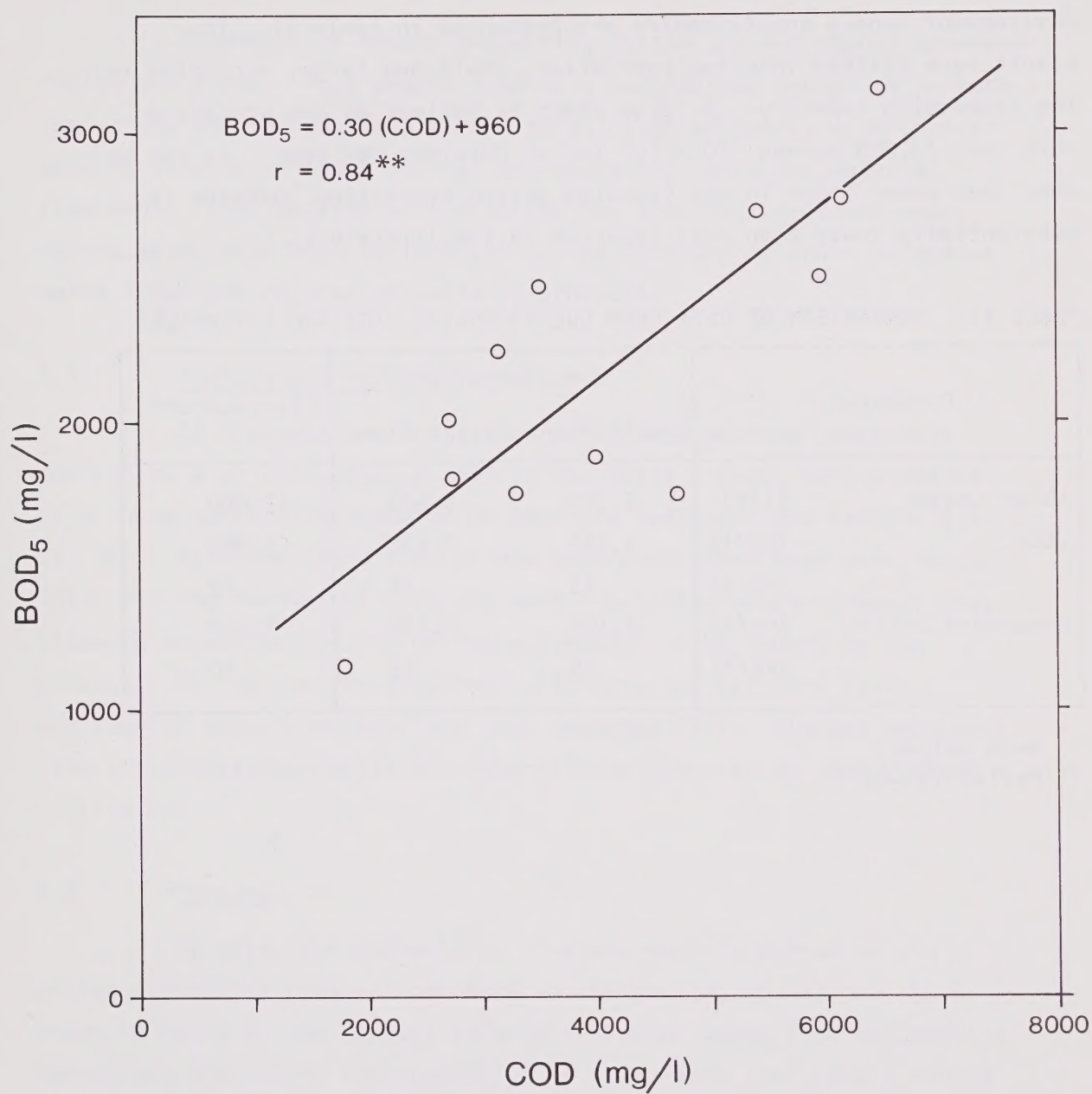


FIGURE 29. RELATION OF BOD_5 TO COD IN TOTAL PLANT EFFLUENTS

** SIGNIFICANT AT 99% CONFIDENCE LEVEL

For comparison purposes, water usage, BOD₅, and suspended solids data reported by the Canadian potato processing industry in the Environment Canada questionnaire are presented in Table 11. The plants were divided into two categories, small and large, according to the processing capacity. A large plant is defined as one processing more than 13,000 tonnes (30×10^6 lb) of potatoes per year. It can be seen that water usage in the Canadian potato processing industry is substantially lower than that reported in the literature.

TABLE 11. COMPARISON OF DATA FROM QUESTIONNAIRE (10) AND LITERATURE

Parameter		Questionnaire*		Literature**
		Small Plant	Large Plant	
Water usage	(l/t)	7,300	6,400	15,000
BOD ₅	(mg/l)	1,750	2,440	1,800
	(kg/t)	13	16	27
Suspended Solids	(mg/l)	2,190	2,350	2,000
	(kg/t)	16	15	30

* Mean values.

** Median values.

5 IN-PLANT MEASURES FOR REDUCTION OF WASTES AND RECOVERY OF BY-PRODUCTS

Treatment of potato processing wastes can and should commence inside the plant. This should lead to a substantial reduction in both the volume and the strength of the total plant effluent, with corresponding returns in lower capital and operating costs for external treatment. This section will describe the in-plant treatment processes which have been implemented by the industry in order to reduce waste loads and recover valuable by-products.

5.1 Fluming and Washing

As discussed earlier, the fluming and washing operations contribute a minimal organic load to the waste stream, making wastes from these operations amenable to separate treatment and recycle (18, 22, 39). Settling tanks and cyclone separators have been used successfully for the removal of silt and sand from these waste streams; thus allowing approximately 70% of the wastewater to be reused in the process. To improve the treatment efficiency of settling tanks, addition of anionic polymer has been reported (41). Sludges separated from these treatment units can generally be disposed on land without difficulty.

5.2 Peeling

To date, the emphasis on in-plant waste clean-up in the potato processing industry has been in the peeling operation. As shown in Table 9, the largest BOD₅ contribution comes from the peeling operation, indicating that reduction in this waste load should result in substantial cost savings in the external treatment system.

The most significant in-plant measure to reduce the waste load in this unit operation is the use of dry caustic peeling. Cyr (17) in the study of dry and conventional caustic peeling methods reported that water usage in dry caustic peeling was approximately 25% of that used in the conventional peeling operation. The BOD₅ and

suspended solids of the waste generated from dry peeling were only 28 and 24%, respectively, of those produced from the conventional peeling method.

In-plant screening of peel wastes through 40 mesh screens has been demonstrated by Krolopp (42). At a flow rate of $18.9 \text{ m}^3/\text{h}$ (the surface area of the screen was not specified), the suspended solids concentration was reduced from 4610 to 1760 mg/l. At $9.6 \text{ m}^3/\text{h}$, it was reduced from 1850 to 800 mg/l. In both cases, approximately 60% of suspended solids were removed by the screen. Because the BOD_5 concentration of the peeler waste is closely related to the suspended solids concentration as indicated in Figure 13, a significant BOD_5 reduction could be anticipated by screening of the peeler waste.

The use of waste potato products for cattle feed is not new. Recently a detailed report on this subject was prepared by the Canada Department of Agriculture (43). The findings indicate that potato wastes with feed supplements are an excellent energy source for cattle. Other studies (39, 41) report on operations where the entire peel waste was segregated from the remainder of the plant wastes and directly combined with undewatered primary clarifier sludge to produce cattle feed. Vacuum filtered primary sludge, largely composed of peel waste, has also profitably been used for cattle feed (18). Generally, wastes from peeling operations are at pH 11 or higher and unsuitable for direct utilization as feed supplement. However, by allowing the peels to ferment, natural bacterial action will reduce the pH to between 6 and 8, thus making them amenable for both enhanced dewaterability and feeding. It is quite evident that in-plant recovery of peel wastes is a practical method for significant waste loads reduction. An additional benefit is cost recovery due to the sale of peelings for cattle feed.

5.3 Slicing

As shown in Table 9, the slicing operation contributes a median BOD_5 load of 5.6 kg/t of potatoes processed. This represents approximately 32% of the total organic load from the three most important unit operations. If the peeler waste is recovered independently, then the waste generated from the slicing operation becomes

the most significant source of pollutants, and in-plant treatment will have substantial effects on the quantity and quality of the total plant effluent.

Studies carried out at the University of Manitoba (25) indicated that removal of suspended solids by centrifugation permitted water reuse in the slicing operation, but 10 to 15% of make-up water was required per cycle. Although multiple reuse of the process water, up to 23 times, did not reduce the overall quality of potato slices, some colour build-up in the liquid was evident but could be removed by activated carbon. Generally, chlorination was required to inhibit microbial growth in the recycled water.

Hydrasieves and hydrocyclones have been recommended for concentrating the dilute starch slurry from the slicer waste, recovering suspended solids and allowing the wastewater to be reused (44). Screens of 0.76 mm (0.03 in) opening have been used to separate the slurry with cyclones used to thicken the slurry. These in-plant measures allowed a return of 90% of the wastewater for reuse.

Reverse osmosis has also been shown to be feasible for concentrating and recovering starch and other soluble compounds in the slicer waste. The concentrate has been used as cattle feed to offset treatment costs (45, 46). Vacuum flash evaporation has been employed in pilot plant studies to concentrate soluble components in the recycled slicer waste (45), but no operating data were available.

5.4 Blanching

Attempts to alter the blanching process to reduce the waste load have been unsuccessful (47). Technology associated with the in-plant treatment of the process waste has not been extensively researched. The problem concerns the soluble nature of the waste constituents, i.e., BOD₅, COD, and dissolved solids. It has been demonstrated (25) that direct water reuse in the blanching process is not feasible, due to the build-up of starch and sugar concentrations as shown in Figure 30. Centrifugation of the recycled water results in a 24% COD removal. A treatment process (25) using 0.7 g aluminum chloride (AlCl₃) per litre of blancher waste combined with centrifugation reduced COD's by

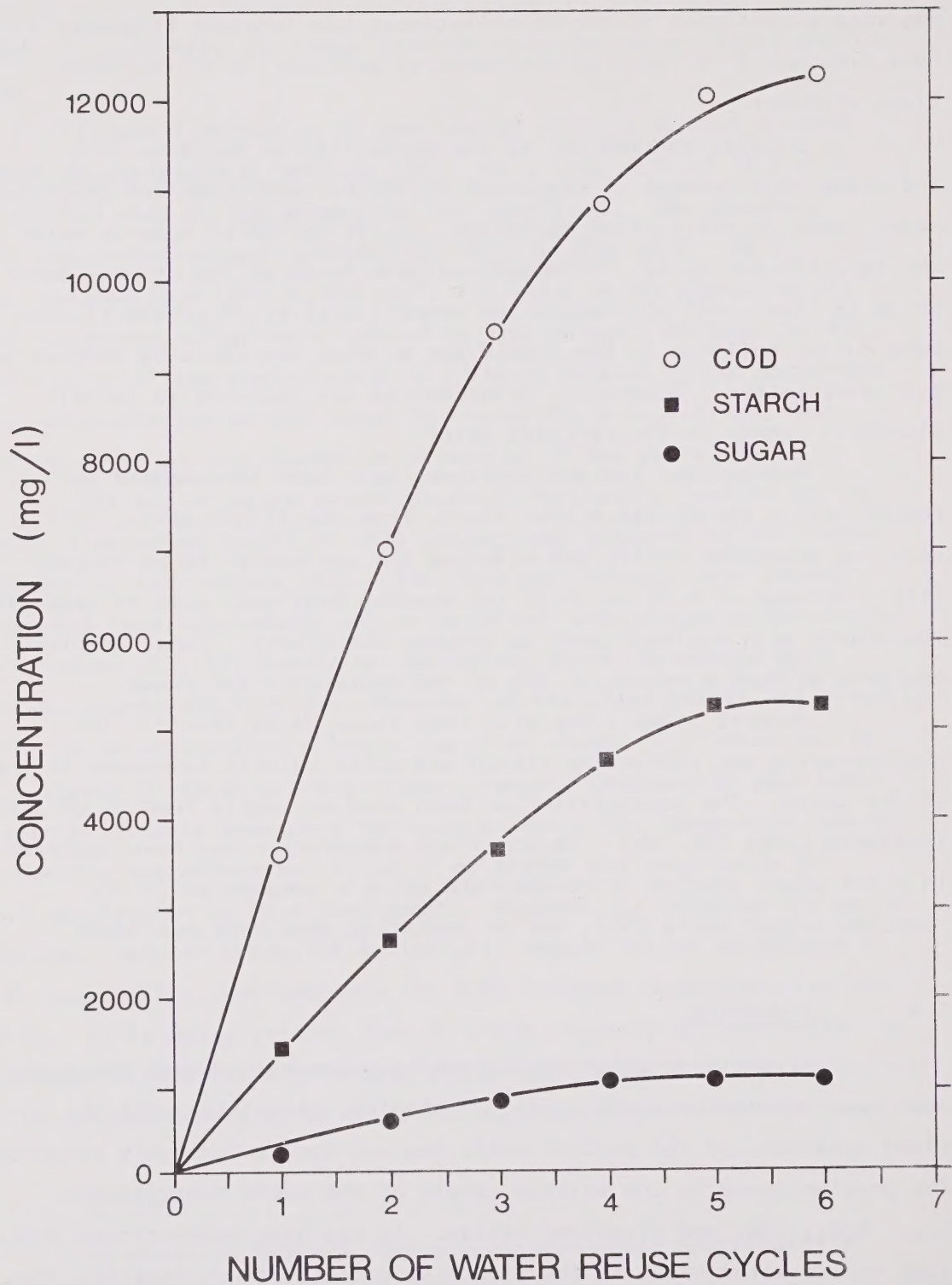


FIGURE 30. RELATION OF COD, STARCH AND SUGAR CONCENTRATIONS TO MULTIPLE REUSE OF THE BLANCHER WASTE (25)

46 to 68%. The addition of 30 g/l powdered activated carbon increased COD removal to about 92%; however, the high carbon dosage would render this method uneconomical. Since blancher waste contributes only 20% of the BOD₅ load of the total plant effluent (Table 9), any potential benefits obtained by the treatment of blancher wastes alone may be outweighed by high cost. Therefore, inclusion of this waste stream in the total plant effluent appears to be the best solution at this time.

6 TECHNOLOGY APPLIED TO TREATMENT OF THE TOTAL PLANT EFFLUENT

It has been shown in Section 4 that potato processing wastes exhibit a high BOD₅ and solids loading. Without treatment, the discharge of the waste will likely result in adverse effects on receiving waters and overloading of municipal waste treatment systems.

Various treatment processes have been used in the past to treat the total plant effluent from the potato processing industry. They include: primary treatment, biological treatment, land application and disposal of sludges generated from these different processes. A detailed discussion of each process is presented in the following sections.

6.1 Primary Treatment

To remove coarse and fine suspended solids, primary treatment of the total plant effluent using coarse screens, fine screens, cyclones and settling tanks has been used in the potato processing industry. Bar screens having openings of 20 mm (3/4 in) or greater are used to prevent coarse objects such as wasted potatoes and potato sprouts from entering the treatment system. Fine screens, varying from 10 to 325 mesh, are employed to remove small particles in the waste stream. Depending on the size of openings, treatment efficiencies ranging from 10 to 85% suspended solids removal have been reported (12, 21, 35). Because the BOD₅ concentration of the total plant effluent is related to the suspended solids concentration as shown in Figure 28, various degrees of BOD₅ reduction have been achieved by fine screens.

Another process variation for suspended solids removal consists of screening followed by hydrocycloning (37). This combination, utilizing 65 mesh screens followed by cycloning of supernatant, reduced suspended solids from 3050 to 280 mg/l. A portion of the treated wastewater was reused in the peeling and washing operations, thereby reducing the water usage by 42%.

The most popular form of primary treatment in the industry has been sedimentation with by-products recovery. Table 12 summarizes

TABLE 12. PRIMARY CLARIFICATION OF THE TOTAL PLANT EFFLUENT

Reference	Overflow Rate ($\text{m}^3/\text{m}^2 \cdot \text{day}$)	COD (mg/l)			BOD ₅ (mg/l)			Suspended Solids (mg/l)		
		In	Out	% Red	In	Out	% Red	In	Out	% Red
37	32.8	5390	2960	45	2730	1600	41	2320	620	73
20	11.9	-	-	-	1605	1035	36	-	-	-
20	11.9	-	-	-	800	570	29	-	-	-
48	33.2	2245	1095	51	1170	595	49	1345	265	80
18	29.9	3300	1250	62	-	-	-	2060	134	94
32	28.7	-	-	-	2000	1000	50	3000	1500	50
31	-	-	-	-	3130	2190	30	4495	2330	57
12	15.6	3150	1470	53	2250	1080	52	1300	395	70
39	14.4	-	-	-	3000	1500	50	3000	255	85
49	-	-	-	-	1280	656	49	3350	226	93

BOD₅, suspended solids and COD removal efficiencies for primary clarifiers treating potato processing wastes as reported in the literature. As indicated, two ranges of overflow rate are evident, one from 12 to 16 m³/m²·day (245 to 325 gpd/ft²·day), and the other from 29 to 34 m³/m²·day (590 to 690 gpd/ft²·day). Analysis of the limited data, collectively or within the two overflow rate ranges, failed to demonstrate a significant linear relationship between the overflow rate and percent BOD₅ or suspended solids removal.

The use of chemical coagulants has not been shown to enhance the efficiency of primary clarification, nor has the replacement of clarification with centrifugation for solids removal been shown economically feasible (36). Air flotation pilot plant studies of the total plant effluent demonstrated 90% suspended solids and 75% BOD₅ removals (36); however, this process has not been adopted by the industry.

As discussed previously, primary clarifier sludge can be recovered and used as cattle feed. Vacuum filtration at a rate of about 1 kg solids/m²·h have been profitably used as an effective means of dewatering and recovering solids for cattle feed (18, 20, 27, 43). High sludge pH problems have been overcome by clarifier designs that allow sludge to ferment in the hopper for approximately 20 hours, thereby reducing the pH to a range of 6 to 8.

Where the amount of grease and oil is high, such as in the waste stream from the french fry operation, grease traps have been installed to protect sewers, pumps and downstream treatment facilities.

6.2 Biological Treatment

Because potato processing wastes contain high concentrations of readily biodegradable compounds, they are most often treated by biological processes. Methods used include conventional and modified activated sludge systems, trickling filters with conventional or synthetic media, aerated lagoons and waste stabilization ponds. Recently, there has been growing interest in the use of rotating biological contactors as a treatment alternative.

6.2.1 Activated sludge

The activated sludge process has been the most widely used biological treatment process in the potato processing industry. It has been used independently as a major treatment system or combined with other processes such as trickling filters or aerated lagoons to provide various degrees of treatment. Results of bench, pilot and full scale operations of activated sludge treatment as reported in the literature are summarized in Table 13.

Bench scale studies by Atkins and Sproul (28) showed that at organic loadings of 1.4, 1.1 and 1.0 kg BOD₅/kg MLSS•day with corresponding detention times of 8, 12 and 6 hours, 96 to 98% BOD₅ and 85 to 93% suspended solids reductions were achieved in completely mixed activated sludge systems. At the first and second loading rates, the pH of the raw waste was approximately 12, but dropped to 8.4 after the activated sludge treatment. This was attributable to the buffering capacity of the carbon dioxide produced in the treatment system. A preliminary study on the feasibility of using the contact stabilization process for the treatment of potato processing wastes indicated that 80% of the COD was removed (28). The detention time in the contact and stabilization tanks was one and eight hours, respectively.

Pilot plant studies (48) demonstrated that potato processing wastes could be treated in a completely mixed activated sludge system. The plant consisted of a coarse screen, a 0.9 m³ (200 gal) primary clarifier, a 3.8 m³ (850 gal) aeration tank and a 1.2 m³ (270 gal) secondary clarifier. The aeration tank was loaded at 0.4, 0.8, 1.1, 1.4 and 1.5 kg BOD₅/kg MLSS•day. No significant difference in the treatment efficiency in terms of BOD₅ and suspended solids removals was found at loadings up to 1.4 kg BOD₅/kg MLSS•day; however, sludge bulking was encountered at loadings higher than 0.8. The performance data at this critical loading are presented in Table 13, indicating 62% BOD₅ and 86% suspended solids reductions.

Black (50), in the pilot scale biodegradability study of potato wastes, indicated that 95% BOD₅ reduction was achieved at the organic loading of 0.4 kg BOD₅/kg MLSS•day. When the loading was

TABLE 13. ACTIVATED SLUDGE TREATMENT OF POTATO PROCESSING WASTES

Reference	Organic Loading (kgBOD ₅ /kgMLSS•day)	Volumetric Loading (kgBOD ₅ /m ³ •day)	Retention Time (hr)	pH		COD (mg/l)		BOD ₅ (mg/l)		SS (mg/l)		Remarks
				In	Out	In	Out	In	Out	In	Out	
28	1.4	5.1	8	8.0	8.1	2220	152	1800	75	300	44	Bench Scale
28	1.1	4.4	12	12	8.4	2110	125	2160	37	400	30	
28	1.0	4.0	6	12	8.4	1480	146	1030	22	420	50	
48	0.8	2.8	4.8	10.3	7.9	900	335	505	190	345	50	Pilot Scale
50	0.4	1.8	4.5	9.3	7.7	1650	103	410	19	364	24	
50	1.0	4.4	2.8	9.5	8.1	1030	64	595	11	520	18	
39	0.3	1.8	22.0	-	-	-	-	1500	68	450	-	Full Scale
12	1.2	4.0	6.4	6.6	7.6	1470	424	1080	268	395	79	
24	0.2 - 0.5	-	-	9.3	7.8	3050	380	1680	85	1480	160	

increased to 1.0 kg BOD₅/kg MLSS•day, slightly better treatment efficiency was obtained; however, bulking sludge problems were encountered. Although the critical loading rate at which problems with poor settling sludge would occur was not investigated, it was considered that an organic loading of greater than 0.5 kg BOD₅/kg MLSS•day would be impractical for the treatment of this type of wastewater.

A full scale activated sludge system has been used successfully in the treatment of the total plant effluent at Salada Foods Limited, Alliston, Ontario (39). The treatment system consists of two 450 m³ (15,900 ft³) aeration tanks and a 720 m³ (25,400 ft³) secondary clarifier. After primary clarification, the average BOD₅ and suspended solids concentrations of the potato waste were 1500 and 450 mg/l, respectively. The aeration tanks, operated in parallel at 22 hours detention time, contained 6000 mg/l of mixed liquor suspended solids with the corresponding loading being 0.3 kg BOD₅/kg MLSS•day. The treated effluent having an average BOD₅ of 68 mg/l was discharged to an aerated lagoon for polishing. According to the treatment plant operator, no operational problems were encountered at the loading of 0.3 kg BOD₅/kg MLSS•day.

Operation of the same activated sludge system at a substantially higher organic loading of 1.2 kg BOD₅/kg MLSS•day resulted in poor performance as shown in Table 13 (12). Solids-liquid separation problems caused by filamentous growth and occasional discharge of high pH peeler wastes into the treatment system were encountered.

Another operation of a full scale activated sludge system was reported by Richter (24). Two aeration basins having a capacity of 4800 and 9600 m³ (170,000 and 340,000 ft³), respectively, were operated in parallel. Primary clarified potato waste with a median pH value of 9.3 was fed to the aeration basins and treated at loadings ranging from 0.2 to 0.5 kg BOD₅/kg MLSS•day. No significant difference in the treatment efficiency was observed at the loading ranges investigated. The average operating results are presented in Table 13. Problems encountered in the study have been primarily associated with sludge bulking which was considered to be attributable to oxygen deficiency in the aeration basins. By increasing the dissolved oxygen

level and reducing the organic loading, successful control of the bulking sludge problem was reported (24).

6.2.2 Trickling filters

Although both conventional and synthetic media trickling filters have been used in the treatment of potato processing wastes, the latter have been found to be more applicable for the treatment of this high strength wastewater. The use of single-stage or two-stage filters depends on the strength of wastes and the degree of treatment required. To improve the treatment efficiency, recycling of part of the effluent is generally employed in high rate trickling filters. Compared to the activated sludge process, the trickling filter offers advantages of lower operating cost, smaller land requirement and faster recovery from shock loads.

Pilot scale treatment of potato wastes using a synthetic media filter has been reported by Pailthorp and Filbert (40). The primary clarified effluent having a BOD_5 concentration of 1680 mg/l was reduced to 280 mg/l at an organic loading of $2.1 \text{ kg } BOD_5/\text{m}^3 \cdot \text{day}$ ($156 \text{ lb } BOD_5/1000 \text{ ft}^3 \cdot \text{day}$). A circulation ratio of 2.5 to 1 was used in the study.

In the treatment of total plant effluents from a mashed potato plant, Allen (32) reported 86% BOD_5 removal in a full scale two-stage trickling filter system. Both filters filled with synthetic media, were 7.3 m (24 ft) in depth and 1080 m^3 ($38,400 \text{ ft}^3$) in volume. The first stage was loaded at $2.6 \text{ kg } BOD_5/\text{m}^3 \cdot \text{day}$ ($156 \text{ lb } BOD_5/1000 \text{ ft}^3 \cdot \text{day}$), but the loading in the second stage was not specified. Insufficient data in the report prevented calculation of organic loading for the second stage. The performance data are shown in Table 14.

Another full scale operation of a two-stage trickling filter system was reported by Landine and Dean (20). Each filter was filled with 900 m^3 ($32,000 \text{ ft}^3$) of synthetic media and equipped with a fixed-nozzle distribution system. An overall treatment efficiency of 86% BOD_5 removal was achieved at the hydraulic loading of $57 \text{ m}^3/\text{m}^2 \cdot \text{day}$

TABLE 14. TRICKLING FILTER TREATMENT OF POTATO PROCESSING WASTES

Reference	Type	Depth (m)	Organic Loading (kgBOD ₅ /m ³ ·day)	Hydraulic Loading (m ³ /m ² ·day)	Recirculation Ratio	pH		BOD ₅ (mg/l)		SS (mg/l)		Remarks
						In	Out	In	Out	In	Out	
40	Single-stage (synthetic media)	-	2.1	-	2.5:1	8.9	7.3	1680	280	648	-	Pilot Scale
32	Two-stage (synthetic media)	7.3 for both stages	2.6 (first stage)	36.8 for both stages	1:1 for both stages	6.8	7.8	480	61*	160	39	Full Scale
20	Two-stage (synthetic media)	6.1 for both stages	4.6 (first stage)	57.0 for both stages	1:1-2:1 for	6.7	7.8	1035	147*	-	140	Full Scale
51**	Single-stage (rock)	2.0	0.06-0.5	0.1-0.9	0	6.2	-7.8	3500	180-350	-	-	Pilot Scale
51**	Single-stage (rock)	2.0	0.2-1.2	3.8-11.4	10:1	6.2	-7.8	3500	180-350	-	-	Pilot Scale

* Final effluent.

** Treatment of potato starch wastes.

(1040 gpd/ft²). The organic loading to the first filter was 4.6 kg BOD₅/m³·day (276 lb BOD₅/1000 ft³·day) and that to the second stage was not specified. Operational problems such as clogging of filter nozzles and ice formation on filter surface were encountered.

Pilot scale treatment of potato starch manufacturing wastes using a conventional trickling filter has been carried out by Buzzell et al (51). The filter, 2 m (6 ft 9 in) deep and 15 cm (6 in) in diameter, was filled with 2 cm (3/4 in) crushed quartzite. Without recirculation, 90 to 95% BOD₅ reduction was attained at organic loadings ranging from 0.06 to 0.5 kg BOD₅/m³·day (3.6 to 30 lb BOD₅/1000 ft³·day). With recirculation, the filter could be operated at substantially higher loadings to achieve the same degree of treatment (Table 14). Attempts to operate the filters at loadings greater than 1.2 kg BOD₅/m³·day (72 lb BOD₅/1000 ft³·day) were unsuccessful due to clogging of the filter media.

6.2.3 Aerated lagoons

The aerated lagoon is a biological treatment process with the aeration basin having a large volume. Oxygen and agitation are provided by either diffused aeration systems or surface aerators. Although the process has been used in the treatment of potato processing wastes for many years, there is a lack of good operating data.

Aerated lagoons are either used independently or combined with other treatment systems to provide a high degree of treatment. In many cases, they are followed by a waste stabilization pond (Section 6.2.4) to reduce effluent suspended solids. Because of its large volume, an aerated lagoon, compared to an activated sludge system, is less susceptible to shock loads; however, it is more sensitive to temperature changes, due to the low solids concentration in the aeration basin and the low liquid temperatures resulting from the large surface area.

Pilot scale treatment of potato processing wastes using an aerated lagoon has been carried out by Dostal (37). The lagoon, 12 m (40 ft) square and approximately 3 m (10 ft) deep was equipped with a

10 hp surface aerator. Primary clarified effluent was treated in the lagoon operated at 189, 210 and 440 kg BOD₅/ha•day (174, 193 and 405 lb BOD₅/acre•day). Results are shown in Table 15. As indicated, treatment efficiencies at 189 and 210 kg BOD₅/ha•day were about the same, with the BOD₅ reduction being approximately 80%. When the loading was increased to 440 kg BOD₅/ha•day, a substantial drop in BOD₅ reduction was observed. As in most aerated lagoons, there was a significant increase in the effluent suspended solids concentration after the treatment.

At Salada Foods Limited, Alliston, Ontario, an aerated lagoon was used to polish effluents from an activated sludge system treating potato wastes (12). The lagoon was operated at 350 kg BOD₅/ha•day (320 lb BOD₅/acre•day) and 74% BOD₅ reduction was achieved (Table 15).

Effluent BOD₅ concentrations as low as 30 mg/l have been reported in an aerated lagoon with a detention time of 82 days (5). Unfortunately, other design data such as dimensions and the organic loading on the lagoon were not specified.

6.2.4 Waste stabilization ponds

Waste stabilization ponds, also called lagoons or oxidation ponds, have been used for the treatment of potato processing wastes where large areas of land are available. The process offers a significant advantage over other treatment methods because of the low construction and operating costs. Based on biological activity, waste stabilization ponds can be classified as aerobic, facultative and anaerobic.

The aerobic stabilization pond depends on surface reaeration and photosynthesis for oxygen supply. It is usually constructed with a depth of 1 to 1.5 m (3 to 5 ft) to allow penetration of sunlight to the bottom to stimulate algal growth. This type of pond is generally not suitable for areas having severe winter conditions because ice formation would render the system inoperative.

TABLE 15. AERATED LAGOON TREATMENT OF POTATO PROCESSING WASTES

Reference	Depth (m)	Area (m ²)	Retention Time (days)	Organic Loading (kgBOD ₅ /ha•day)	pH		COD (mg/l)		BOD ₅ (mg/l)		Suspended Solids (mg/l)		Remarks		
					In	Out	In	Out	%Red	In	Out	%Red		In	Out
37	3.0	150	10.4	189	6.5	8.3	2390	1190	50	1700	310	82	310	650	Pilot Scale
37	3.0	150	7.8	210	6.4	8.6	2210	860	61	1410	270	81	490	630	Pilot Scale
37	3.0	150	4.2	440	6.5	8.3	2160	1480	31	1580	710	55	470	700	Pilot Scale
12	2.4	21900	13.4	350	7.6	7.8	424	190	55	270	70	74	79	80	Full Scale
5	-	-	82	-	-	-	-	-	-	1000	30	97	-	-	Full Scale

No information is available with respect to the use of facultative waste stabilization ponds for the treatment of potato wastes and only three publications (12, 38, 41) dealing with anaerobic stabilization ponds were identified in the literature.

Vivian and Dostal (38) carried out a pilot scale study using an anaerobic waste stabilization pond to treat primary clarified potato wastes. The pond, having a capacity of 170 m^3 (37,000 gal), was operated at loadings of 770, 1360 and 2830 kg $\text{BOD}_5/\text{ha}\cdot\text{day}$ (708, 1250 and 2600 lb $\text{BOD}_5/\text{acre}\cdot\text{day}$). Performance data are presented in Table 16, indicating that minimal BOD_5 reduction was achieved in the system. When effluents from this pond were discharged to an aerated lagoon of the same capacity, an overall treatment efficiency of 81 to 95% BOD_5 reduction was achieved in the combined system.

The original treatment plant at Salada Foods Limited, Alliston, Ontario, used an anaerobic waste stabilization pond to treat its potato processing waste (12). Because of the poor performance and odour problems, this pond was converted to an aerated lagoon in 1963. Operating results of the pond before the change was made are presented in Table 16. Comparing the results shown in the table, it can be seen that there is a decrease in treatment efficiency with increasing organic loadings.

Treatment of combined wastewaters from municipal and potato processing wastes using anaerobic stabilization ponds has been reported by Fossum (41). The BOD_5 and suspended solids concentrations of the combined waste averaged 800 to 500 mg/l. At the organic loading of 3400 kg $\text{BOD}_5/\text{ha}\cdot\text{day}$ (3130 lb $\text{BOD}_5/\text{acre}\cdot\text{day}$), 30% BOD_5 and 85% suspended solids were removed in the system. Operational problems such as offensive odours and icing in the winter operation have been reported.

6.2.5 Rotating biological contactors (RBC)

A pilot plant evaluation of RBC treatment of simulated potato processing wastes has been reported by Cochrane and Dostal (52). The RBC used for the study was a six-stage unit consisting of 36 polystyrene discs, each of 60 cm (2 ft) diameter. The BOD_5 and

TABLE 16. WASTE STABILIZATION POND TREATMENT OF POTATO PROCESSING WASTES

Reference	Depth (m)	Area (m ²)	Retention Time (days)	Organic Loading (kgBOD ₅ /ha·day)	COD (mg/l)			BOD ₅ (mg/l)			Suspended Solids (mg/l)			Remarks
					In	Out	%Red	In	Out	%Red	In	Out	%Red	
38	3.0	150	8.8	770	3400	2280	33	1680	1260	25	740	130	82	Pilot Scale
38	3.0	150	5.0	1360	3400	2890	15	1680	1480	12	740	480	35	Pilot Scale
38	3.0	150	2.4	2830	3400	2890	15	1680	1460	13	740	360	52	Pilot Scale
12	2.4	21900	27	110	-	-	-	1650	620	62	1260	250	80	Full Scale
41*	4.5	9300	8.0	3400	1100	660	40	800	560	30	500	75	85	Full Scale

* Treatment of combined wastes from municipal and potato processing wastes.

suspended solids concentrations of the synthetic waste ranged from 510 to 1790 mg/l and 184 to 356 mg/l, respectively. At the three organic loadings investigated; namely, 5.3, 16.8 and 45.0 g BOD₅/m²·day (1.1, 3.4 and 9.0 lb BOD₅/1000 ft²·day), 81 to 91% of BOD₅ and 54 to 76% of suspended solids were removed. Effluent BOD₅ concentrations varied from 99 to 198 mg/l and suspended solids from 70 to 124 mg/l. Although the effluent quality was below the level which is generally considered acceptable for discharge to receiving waters, the study indicated that the RBC was an efficient treatment process for synthetic potato wastes. Further studies in this area are required.

6.3 Sand Filtration

Sand filtration of biologically treated effluents has been used to polish the effluents for reuse in the potato processing plant. In one study (32), biologically treated effluent with a BOD₅ concentration of 23 mg/l was applied to a sand filter at a loading rate of 182 m³/m²·day (3640 gpd·ft²). It was reported that the effluent BOD₅ concentration was 2 to 5 mg/l and suspended solids were not detectable. A portion of the filtered effluent was chlorinated and reused in the process. In the other study (53), effluents from an activated sludge system were filtered through two dual-media filters filled with anthracite and sand. Part of the filtrate was reused in the potato processing plant, resulting in a 25% reduction in water usage. One problem associated with recycle has been the build-up of sodium, phosphate and chloride in the process water.

6.4 Advanced Treatment Methods

Advanced waste treatment has been primarily directed towards wastes from the potato starch industry. However, it has been suggested that advanced treatment methods have potential application in other sectors of the industry (5, 36). These include reverse osmosis (54, 55, 56), ion exchange (54, 57, 58), evaporation (59, 60) and protein coagulation (45, 55, 59, 61). Evaporation and reverse osmosis have been used for the recovery of protein and other compounds from the

slicer waste of french fry and potato chip plants (45). Suspended starch can also be concentrated by these techniques. The reclaimed starch can be used as cattle feed, in the manufacture of adhesive products, and sizing for paper (62). Cost comparisons indicated that the advanced treatment methods were more costly than the biological treatment processes and would be more suitable for in-plant treatment of wastes for by-product recovery and water reuse (5, 36, 45).

6.5 Land Disposal

In areas where sufficient land and suitable soil are available, application of potato processing wastes to the soil provides an alternative for waste disposal. Potato wastes contain significant amounts of potassium, nitrogen and phosphorus which are beneficial soil fertilizers. As the sodium ions in the waste tend to build up in the soil, clogging the pores, caution should be exercised to control the discharge of caustic peeler wastes. For wastes high in suspended solids, pretreatment such as screening is generally required.

In the United States, 21% of the potato processors in the canning and freezing sectors dispose of their wastes by spray irrigation (5). A comprehensive study on spray irrigation of screened (40 mesh) potato wastes has been reported by Haas (63). A 9 cm (3.5 in) application rate was used over one day followed by a nine-day rest period. The hydraulic loading on a 48-hectare (120-acre) area was approximately $9 \text{ m}^3/\text{ha}\cdot\text{day}$ (8000 gal/acre·day). Winter operation was described as feasible at ambient temperatures as low as -15°C . The effect of land disposal on ground water was not investigated.

6.6 Handling and Disposal of Sludges from Biological Treatment Systems

Most biological treatment systems produce an excess of sludge during the removal of soluble organic substrates from waste streams. The waste sludge generally contains 95 to 99% water and 60 to 80% organic solids. It is very bulky and readily putrescible.

Therefore, it is essential to remove the water and stabilize the organics in the sludge before final disposal. Unlike the solids removed in the primary clarifier, sludges generated in biological treatment systems have not been utilized for cattle feed.

Several methods for sludge handling have been reported by Richter et al (64). The study involved pilot scale evaluations of centrifugation, drum drying, vacuum filtration and aerobic digestion of the sludge generated from an activated sludge system treating potato processing wastes. A basket centrifuge operated at 3.7 to 14.8 l/min (0.8 to 2.3 gpm) was shown to recover 80 to 94% solids, producing a cake with 3.7 and 6.0% solids content, respectively. The drum dryer was capable of further dewatering sludge cake to 80 to 90% dry solids. Vacuum filtration, with and without chemical addition, was demonstrated to be ineffective in dewatering the waste sludge. Aerobic digestion with 17 days detention time reduced 55% of volatile solids and significantly improved the dewaterability of the sludge. Cationic polymer addition allowed dewatering of aerobically digested sludge on 50 mesh vibrating screens and resulted in a cake with 4% solids. The effluent contained 20 mg/l suspended solids. Basket centrifugation of aerobically digested sludge achieved 93% solids recovery, producing a cake with 7.6% solids concentration.

Air flotation of ferric chloride conditioned sludge was reported to increase solids from a range of 0.5 to 1.5%, to 3 to 4% solids (65). Gravity thickening in combination with vacuum filtration has achieved varying degrees of success in dewatering the excess biological sludge (9, 24, 32); however, no operating data are available. Dewatering of the sludge generated from trickling filters has been successful by rotary vacuum filtration and chemical conditioning using lime and ferric chloride (20).

Land disposal of waste sludge, with or without treatment, has been used in the potato processing industry. Direct land disposal of excess sludge from an activated sludge system has been practised by Salada Foods Limited in Ontario (12). However, no operating data are available. A pilot scale study carried out by Richter et al (64)

indicated that direct spray irrigation of sludges from the potato waste treatment system was successful up to loadings of approximately 80 kg BOD₅/ha•day (70 lb/acre•day) and 190 kg suspended solids/ha•day (178 lb/acre•day). Odours were not a problem if the specified loadings were not exceeded. However, it was indicated that the build-up of sodium ions in the soil due to the discharge of caustic peeling wastes must be controlled. To avoid clogging of sprinklers, screening of sludges before spraying was recommended.

6.7 Summary

The literature review has indicated that many alternatives are available for the treatment of potato processing wastes. The most popular and successful treatment method appears to be the one employing a coarse screen followed by a primary clarifier and biological treatment. High treatment efficiency in terms of BOD₅ and suspended solids has been achieved in the conventional activated sludge system. Because of insufficient data, it was impossible to establish a relationship between organic loadings and treatment efficiency. Due to the bulking sludge problem encountered, it must be concluded that the high rate activated sludge system is impractical for the treatment of potato processing wastes.

REFERENCES

1. Canada. Statistics Canada, Canada Year Book, 1972, Statistical Annual of the Resources, Demography, Institutions and Social and Economic Conditions of Canada, Ottawa, 1973.
2. Canada. Statistics Canada, "Farm Cash Receipts, December 1973" Agriculture Division, Farm Income and Prices Section, 34(12):13, 1974.
3. Hatfield, F.H., "A Survey of the Production, Use and Disposal of Potatoes in Canada", Proceedings International Symposium Utilization and Disposal of Potato Wastes, New Brunswick, May, 1965, New Brunswick Research and Productivity Council, 1966.
4. Whitney, L., "Eliminating Water Pollution", Proceedings of the Production and Technical Division Meetings of the Potato Chip Institute International, Bal Harbour, Florida, 1971.
5. National Canners Association, "Liquid Wastes from Canning and Freezing Fruits and Vegetables", Water Pollution Control Research Series, EPA #12060 EDK 08/71, 1971.
6. Talburt, W.F., O. Smith, Potato Processing, Avi Publishing Co., Westport, Conn., 1967.
7. Kice, J.L., E.N. Marvel, Modern Principles of Organic Chemistry, The Macmillan Co., New York, 1966.
8. Greenwood, C.T., "Structure, Properties and Amylolytic Degradation of Starch", Food Technology, 18(5):138, 1964.

9. Banerji, S.K., B.E. Ewing, R.S. Engelbrecht, R.E. Speece, "Mechanism of Starch Removal in Activated Sludge Process", Proceedings of the 21st Industrial Waste Conference, Purdue University, Lafayette, Indiana, 1966.
10. Bisset, W., "An Inventory of the Potato Processing Industry in Canada", Environmental Protection Service Internal Report, 1974.
11. Canada. Statistics Canada, Miscellaneous Food Processors, Annual Census of Manufactures, October, 1973.
12. Armstrong, T.D., B.I. Boyko, "Treatment of Potato Processing Wastes at Salada Foods Limited, Alliston", Proceedings 16th Ontario Industrial Waste Conference, Niagara Falls, Ontario, 1969.
13. Cansfield, P.E., R.A. Gallop, "Conservation, Reclamation and Re-Use of Solids and Water in Potato Processing", Proceedings of the 17th Ontario Industrial Waste Conference, Niagara Falls, Ontario, 1970.
14. Graham, R.P., C.C. Huxsoll, M.R. Hart, M.L. Weaver, A.I. Morgan, "Dry Caustic Peeling of Potatoes", Food Technology, 23(2):195, 1969.
15. Willard, M., "Prevention of Production of Pollutants", Proceedings of the Production and Technical Division Meetings of the Potato Chip Institute International 1972-1973, 1973.
16. Willard, M., "Pilot Plant Study of the USDA - Magnuson Infra-Red Peeling Process", Proceedings 19th National Potato Utilization Conference, Big Rapids, Michigan, p. 105, July 1969.

17. Cyr, J.W., "Progress Report: Study of Dry Caustic Versus Conventional Caustic Peeling and the Effect on Waste Disposal", Proceedings 2nd National Symposium on Food Processing Wastes, Water Pollution Control Research Series, EPA #12060 03/71, p. 129, 1971.
18. Grames, L.M., R.W. Kueneman, "Primary Treatment of Potato Processing Wastes with By-Product Feed Recovery" Journal Water Pollution Control Federation, 41(7):1358, 1969.
19. Cooley, A.M., E.D. Wahl, G.O. Fossum, "Characteristics and Amounts of Potato Wastes from Various Process Streams", Proceedings of the 19th Industrial Waste Conference, Purdue University, Lafayette, Indiana, p. 379, 1964.
20. Landine, R.C., J.R. Dean, "Waste Treatment and Solids Recovery System for the French Fried Potato Processing Plant", Proceedings of the 19th Ontario Industrial Waste Conference, Toronto, Ontario, p. 44, 1972.
21. Formo, H.G., "Problems and Approaches in the Treatment of Wastes from Potato Processing Plants", Proceedings 10th Pacific Northwest Industrial Waste Conference, p. 235, 1961.
22. Smith, H.S., "Potato Waste Treatment Research Needs", Potato Waste Treatment Symposium, U.S. Department of the Interior, Federal Water Pollution Control Administration, Northwest Region, Pacific Northwest Water Laboratory, Corvallis, Oregon, p. 61, March 1968.
23. Ambrose, T.W., C.O. Reiser, "Wastes from Potato Starch Plants", Industrial and Engineering Chemistry, 46(6):1331, June 1954.

24. Richter, G.A., "Aerobic Secondary Treatment of Potato Processing Wastes", EPA Water Pollution Control Research Series, 12060 04/70, p. 39, 1970.
25. Gallop, R.A., A.W. Hydamaka, Water Management Systems for Potato Processing Plants, Environment Canada Service Contract #0GR2-0403, p. 142, August 1973.
26. Sproul, O., "Potato Processing Waste Treatment Investigations at the University of Maine", International Symposium Utilization and Disposal of Potato Wastes Proceedings, New Brunswick Research and Productivity Council, May 1965, 1966.
27. Peters, H., "Measures Taken Against Water Pollution in Starch and Potato Processing Industries", International Congress on Industrial Wastewater, Stockholm, p. 129, 1970.
28. Atkins, P.F., O.J. Sproul, "Feasibility of Biological Treatment of Potato Processing Wastes", Proceedings of the 19th Industrial Waste Conference, Purdue University, Lafayette, Indiana, p. 303, May 1964.
29. Porges, R., "Waste Loadings from Potato Chip Plants", Sewage and Industrial Wastes, 24(8):1001, 1952.
30. Buchzik, C.M., "Clean up of Emissions", Proceedings of the Production and Technical Division Meetings of the Potato Chip Institute International 1972-1973, p. 4, 1973.
31. Francis, R.L., "Characteristics of Potato Flake Processing Wastes", Journal Water Pollution Control Federation, 34(3): 291, 1962.

32. Allen, T.S., "Water Reuse in the Food Processing Industry", Transactions of the ASME, Journal of Engineering for Industry, p. 1094, November 1972.

33. Holdsworth, S.D., "Effluents from Fruit and Vegetable Processing, Part 1", Effluent and Water Treatment Journal, 10(3):131, 1970.

34. Jennings, R.J., "The Sweco Centrifugal Wastewater Concentrator: A New More Cost Effective Means of Treating Potato Processing Effluent", Canadian Potato Chip Association Environmental Seminar, Toronto, Ontario, 9, March 1973.

35. Buchzik, C.M., "A Process for Managing Wastewater from Potato Chip Plants", Canadian Potato Chip Association Environmental Seminar, Toronto, Ontario, p. 5, March 1973.

36. Guttormsen, K., D.A. Carlson, "Status and Research Needs of Potato Processing Wastes", Proceedings 1st National Symposium on Food Processing Wastes, EPA Water Pollution Control Research Series, 12060 04/70, p. 27, 1970.

37. Dostal, K.A., "Secondary Treatment of Potato Processing Wastes", EPA Water Pollution Control Research Series, 12060 07/69, 1969.

38. Vivian, R.W., K.A. Dostal, "Potato Processing Wastes: Progress Report on Pilot Plant Studies of Secondary Treatment", U.S. Department of the Interior, Federal Water Pollution Control Association Northwest Region, Pacific Northwest Water Laboratory, Corvallis, Oregon, Report No. PR-4, January 1968.

39. Robson, A., Personal Communication, 1974.

40. Pailthorp, R.S., J.W. Filbert, "Design of Biological Oxidation Systems Continued - II Performance of Pilot Scale Treatment Plants, Especially for Potato Wastes", Proceedings International Symposium Utilization and Disposal of Potato Wastes, Fredericton, New Brunswick, May 1965, p. 285, 1966.
41. Fossum, B., "Pretreatment of Combined Municipal and Potato Processing Wastes", Proceedings 4th National Symposium on Food Processing Wastes, Environmental Protection Technology Series, EPA-660/2-73-031, p. 326, December 1973.
42. Krolopp, O.C., "Raw Potato Slice Washing and Wastewater Cleanup", Canadian Potato Chip Association Environmental Seminar, Toronto, Ontario, March 1973.
43. Nicholson, J.W.G., Guidelines for Feeding Potato Processing Wastes and Culls to Cattle, Canada Department of Agriculture Publication No. 1527, p. 17, 1974.
44. Taylor, J.A., "Bauer Equipment for the Potato Chip Producing Industries, Design and Application", Canadian Potato Chip Association Environmental Seminar, Toronto, Ontario, p. 10, March, 1973.
45. Hautala, E., M.L. Weaver, "Reuse of Water and Reclamation of Nutrients from Potato Cutting Wastes", Proceedings of the 20th Annual National Potato Utilization Conference, Riverside, Calif., p. 77, July 1970.
46. Payne, J.M., "Ropak Reverse Osmosis and Its Application to Starch Removal from Liquid Streams", Canadian Potato Chip Association Environmental Seminar, Toronto, Ontario, p. 5, March 1973.

47. Lund, D.B., "Wastewater Abatement in Canning Fruits and Vegetables by IQB Blanching", EPA #660/2-74-006, April 1974.
48. Canada, Department of National Health and Welfare, "Pilot Plant Study of Potato Processing Waste by Complete Mix Activated Sludge Process", Division of Public Health Engineering, Department of National Health and Welfare, Atlantic Region, Moncton, New Brunswick, 1969.
49. Industrial Waste Guide for the Potato Chip Industry, Potato Chip Institute International, Cleveland, p. 16.
50. Black, S.A., "Biodegradability of Potato Processing Wastes", Division of Research, Ontario Water Resources Commission, Rp 2013, p. 12, January 1968.
51. Buzzell, J.C., A.L. Caron, S.J. Ryckman, O.J. Sproul, "Biological Treatment of Protein Water From Manufacture of Potato Starch, Part 2", Water and Sewage Works, Reference No. R-310, 1964.
52. Cochrane, M.W., K.A. Dostal, "RBC Treatment of Simulated Potato Process Wastes", Proceedings 3rd National Symposium on Food Processing Wastes, Water Pollution Control Research Series, EPA R2-72-018, p. 99, November 1972.
53. Lash, L., "Processing Liquid Wastes in the Potato Industry", Water - 1972, American Institute of Chemical Engineers Symposium Series, 69(129):22, 1972.
54. Heisler, E.G., J. Siciliano, S. Krulick, "Potato Starch Factory Waste Effluents, Part II: Development of a Process for Recovery of Amino Acids, Protein and Potassium", Journal of Science, Food and Agriculture, 23, p. 745, 1972.

55. Heisler, E.G., J. Siciliano, R.H. Treadway, C.F. Woodward, "Recovery of Free Amino Compounds from Potato Starch Processing Water by Use of Ion Exchange", American Potato Journal, 36(1):1, 1959.
56. Heisler, E.G., K. Siciliano, R.H. Treadway, C.F. Woodward, "Recovery of Free Amino Compounds from Potato Starch Processing Water by Use of Ion Exchange, Part II: Large Scale Laboratory Experimentation", American Potato Journal, 39(2):78, 1962.
57. Heisler, E.G., S. Krulick, J. Siciliano, W.L. Porter, J.W. White, "Potato Starch Factory Waste Effluents, I: Recovery of Potassium and Other Inorganic Cations", American Potato Journal, 47(9):326, 1970.
58. Schwartz, J.H., S. Krulick, W.L. Porter, "Potato Starch Factory Waste Effluents ,III: Recovery of Organic Acids and Phosphate", Journal of Science, Food and Agriculture, 23, p. 977, 1972.
59. De Koe, W.J., "Protein Recovery from Potato Starch Mill Effluents", Water and Waste Treatment, p. 55, July/August, 1968.
60. Pellett, R.G., Personal Communication, Raypak Thermionics (Canada) Limited, November 1974.
61. Strolle, E.O., J. Cording, N.C. Aceto, E.S. DellaMonica, "Recovery of Proteins from Potato Starch Factory Effluents: Progress and Prospects", Proceedings of the 20th Annual National Potato Utilization Conference, Riverside, Calif., p. 71, July 1970.

62. Seyfert, J., "Profitable Waste Control for the Potato Chip Industry", Proceedings of the Production and Technical Division Meetings of the Potato Chip Institute International, p. 44, 1973.
63. Haas, F.C., "Spray Irrigation Treatment", Potato Waste Treatment Symposium, U.S. Department of the Interior, Federal Water Pollution Control Administration Northwest Region, Pacific Northwest Water Laboratory, Corvallis, Oregon, p. 55, March, 1968.
64. Richter, G.A., K.L. Sirrine, C.I. Tollefson, "Conditioning and Disposal of Solids from Potato Wastewater Treatment", Journal of Food Science, 38, p. 218, 1973.
65. Richter, G.A., "Aerobic Secondary Treatment of Potato Processing Wastes", Proceedings First National Symposium on Food Processing Wastes, EPA Water Pollution Control Research Series, 12060 4/70, p. 39, April 1970.

ACKNOWLEDGEMENTS

The authors are grateful to Mr. P. Crescuolo, technician of the Ultimate Disposal Unit, WTC, for assistance in gathering information and preparing a summary of reference data.

Dr. N.W. Schmidtke, Head of the Process Development Section, WTC, made many valuable suggestions in the preparation of this report, and his contribution is much appreciated.

